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IN-MINE TESTING OF A NATURAL BACKGROUND SENSOR

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IN-MINE TESTING OF A NATURAL BACKGROUND SENSOR

1.0 SUMMARY

Tests were performed in the laboratory and in an operating mine to demonstrate the capability of a natural background sensor for measuring the thickness of top coal on a longwall face.

The natural background sensor circuitry and hardware developed by the National Aeronautics and Space Administration (NASA) were complemented with collimation and mounting hardware designed by General Electric Corporate Research and Development (CRD) to survive the mine environment and collect significant information from the top coal area only of the roof.

The complete system was installed on a shearer in an operating mine. However, the limitations imposed on the time during which tests could be performed, and the roof conditions at the time were such that the tests did not produce readings of top coal measurements during the shearer operation. Nevertheless, the tests series demonstrated the capability of the system to survive operating conditions in the mine environment, while the static tests confirmed the fact that the natural background sensor approach is a valid method of measuring top coal thickness in mines where the roof rock provides a constant radiation level.

The experience gained during in-mine tests as well as during the laboratory preparations for the tests provide practical results that will improve the results of subsequent development of an integrated vertical control system receiving information from the natural background system.

2.0 INTRODUCTION

This report presents the results of tests made on a natural background sensor developed by NASA for the purpose of measuring the thickness of top coal in mining operations. Calibration and collimation tests were performed on a simulated roof at the General Electric Research and Development Center, followed by tests on a longwall shearer at the York Canyon mine of the Kaiser Steel Company.

Both test series show that the top coal thickness can indeed be determined by the method used, provided that the radiation level is well known and is constant along the mine face. With suitable collimation of a large-area crystal detector, it is possible to eliminate all but the significant radiation source areas and to concentrate on the roof area between the edges of the shields and the face.

Mounting hardware was developed for installing the sensor and its related display and power supply on a shearer. The experience gained in the mine test demonstrated that the electronics as well as the package are capable to survive in the mine environment. Also evident was the need to provide more compact packages because the clearances between the shearer and its surroundings are always limited. In a system where the operator would depend on visual observations of the measurement display, this display needs to be provided in a separate box, nested close to his machine controls. Where the sensor would be incorporated into an automatic vertical control, there would be ample opportunity to optimize the package.

3.0 CALIBRATION AND COLLIMATION TESTS

A test bed was made with a layer of draw slate obtained from the roof of the Bruceton mine, crushed, and spread in a 6 in. (15 cm) box with horizontal dimensions of 6×10 ft (180 \times 300 cm). Two dollies were provided with a strut spanning the bed to allow scanning of the bed by the sensor mounted on the strut. Sheets of 1/4 in. (6.35 mm) hard-temper masonite were obtained to simulate the top coal between the slate and the sensor. In this manner, a convenient and flexible arrangement, free of polluting dust for the laboratory environment, was obtained to evaluate the response of the sensor to step changes in the "coal" thickness. The attenuation provided by the masonite was compared to that of a layer of crushed coal inserted between the shale and the sensor. This arrangement also made it possible to determine the edge of the 100% acceptance and penumbra area provided by the various collimation schemes.

The numerical results of the test bed were somewhat lower than the results obtained in the measurements made with the same sensor at the Bruceton mine, because the 6 in. (15 cm) layer of shale had not yet provided the "saturated" radiation level produced by a very thick rock layer. However, this difference was not a significant factor, since the prime purpose of the simulation bed was to provide a convenient method of checking the operation of the system, its response to step changes, the area of detection, etc., rather than a precise simulation of a particular count rate. Figure 1 shows the test bed arrangement in schematic form; Figure 2 shows a photograph of the complete system as installed in the laboratory.

3.1 Sensor Systems

At the outset of the project, the available sensor used a round crystal, shielded in a cylindrical housing, as documented in NASA Drawing Tree 50M28106, including drawing 50M28113.

This arrangement required that the sensor be mounted with the axis of the cylinder in a near-vertical direction, aiming at the roof area of interest, i.e., between the shield edges and the face. Initial tests with this sensor were made in the laboratory, providing an opportunity to gain experience in the system and determine the validity of the simulated bed method. Simultaneously with the availability of a large-area sensor, layout work on the drawing board indicated the difficulty of fitting the vertical cylinder around an operating shearer. A decision was made, therefore, to proceed with the new sensor design, based on a rectangular crystal of larger area, where collimation could be provided by a deeper well in the shield. Also, the vertical dimensions were reduced by having the photomultiplier located on the side of the crystal, i.e., with its axis 90 degrees from the axis of the detecting window, as opposed to the coaxial arrangement of the cylindrical detector. This new sensor design is documented in NASA Drawing Tree 50M28106, including drawing 50M29442.

3.2 Test Bed Evaluation

The effect of thickness on the radiation level produced by the shale layer was evaluated by a series of three measurements conducted with the 5 in. (12.5 cm) round sensor centered above a layer of shale with thicknesses of 6, 8, and 10 in. (15, 20, and 25 cm) piled in the bed trough. The height of the sensor above the bed in each case was varied between 2 and 10 in. (15 and 25 cm). Figure 3 shows the resulting count rates observed under these conditions. It is apparent that at the 5 in. (15 cm) thickness of shale arbitrarily selected for the uniform test bed, the "saturated" radiation level is not yet reached, while the increase between 8 and 10 in. (20 and 25 cm) is lower than that between 6 and 8 in. (15 and 20 cm). The slope observed for the thicker layers is more likely to be an artifact in the arrangement. The uniform 6 in. (15 cm) layer over the whole test trough provided a more constant radiation as the height of the sensor was increased, while the localized piling of shale under the sensor for the thicker layers produced an apparent drop as the increased sensor height took into view the thinner layer outside of the localized pile. This was the first indication that a narrower angle of collimation would be desirable.

The bed was returned to a uniform 6 in. (15 cm) thickness with the masonite sheets arranged in two stacks, leaving also an area of bare shale. With the use of the dimension definitions given in Figure 1, the count rate measured as the sensor scanned the center of the bed, traversing along the axial distance direction, is shown in Figure 4. Here again, the penumbra effect and wide-angle collimation are apparent in the rounding of the edges of the masonite steps detected by the sensor. Note that at the position where the axis of the sensor is exactly above the rise of the step, the count is predictably the average of the two thicknesses on either side of the step, and that about 20 in. (50 cm) are required for the count rate to stabilize after passing over a step.

3.3 Collimation of the Acceptance Angle

As initially developed by NASA, the cylindrical sensor had an acceptance angle estimated at 135 degrees, a value selected to gain as many counts as possible from a uniform target area. With additional experience from tests conducted at Bruceton by NASA and at CRD under this project, it became apparent that more valuable information could be collected by eliminating counts originating from irrelevant areas and settling for fewer counts originating from the area of real interest, i.e., the narrow band of top coal between the edges of the roof shields and the vertical coal face. The York Canyon tests were conducted with a steel canopy over the sensor window that provided both a protection and sliding surface for coal particles, and a partial shielding from radiation emanating from areas outside the area of interest. Further experience gained there indicated that even tighter collimation would be necessary to obtain readings from a variable distance, as a result of variable roof height over the length of an actual mine face. Therefore, a more restricted sensor canopy was built and used in the initial measurements made at the Old Ben mine.

Figure 5 shows the configuration of the York Canyon face, shearer position, and acceptance angle of the sensor mounted on its bracket. With the shielding provided on the machine side of the canopy, the edge of the 100% acceptance beam was vertical, while the face side of the beam edge was intercepting the vertical face. In an idealized situation, as shown in Figure 5, it was expected that the radiation included in this fringing area would be so heavily attenuated by travelling through the uncut coal that it would be effectively eliminated from the count rate. Consequently, it was expected that largely roof radiation would be detected. Actually, it was found that quite often large sections of the face beyond the path of the drum would collapse, thus reducing the amount of attenuation expected from the "uncut" coal, and thus introducing a potential error in the measurements. This finding gave further motivation to provide tighter collimation.

3.3.1 Edge of Beam Determinations for Large-Area Sensor

The edge of the acceptance beam was determined in the test bed, both laterally and longitudinally, as shown in Figure 6. With the window of the sensor 7 in. (17.5 cm) above the shale surface, a row of lead bricks was progressively moved from the outer area into the presumed angle of acceptance of the sensor, on either the long side (Figure 6a) or on the short side (Figure 6b). Using the edge of the window as a reference, the following counts were recorded:

1. Long side edge:	x	counts	
	in.	cm	per second
	14.5	37	240
	10.5	27	235
	6.5	17	230

2. Short side edge:	y	counts	
	in.	cm	per second
	10	25	239
	8	20	238
	7	17.5	233
	6	15	231
	5	12.5	230

The onset of a count reduction appears around 12 in. (30 cm) on the long side of the beam, and 7.5 in. (19 cm) on the short side. With the height of the window edge at 7 in. (17.5 cm), the angles are respectively 60 degrees and 47 degrees (\tan^{-1} of the ratios) from the axis perpendicular to the window.

3.3.2 Canopy Design

The relatively wide angle still in existence with the collimation provided by the rectangular shield of the sensor made it desirable to add a canopy to the sensor that would both provide a restriction of the beam and provide a slanted surface on which

coal and rock debris would not accumulate. A vibrating sheet of rough Lexan® was tilted at varying angles while wet coal particles were thrown on the surface. A minimum angle of 45 degrees from the horizontal was found necessary to prevent accumulation of coal on the canopy, with of course more positive sliding off at greater angles.

With the concern for ruggedness always present in the design, there was a need to effect a trade-off between thickness of the window cover and the resultant count loss. Several thicknesses of Lexan material were inserted between the sensor window and the shale bed, as follows:

Thickness of Lexan	0	1/8 in. (3.2 mm)	1/4 in. (6.4 mm)	1/2 in. (13 mm)
Counts per second	240	236	233	226

A crude impact test was performed, dropping a lead brick on the 1/4 in. (6.4 mm) sheet of Lexan, from a height of 6 feet (180 cm), mounted on a finished canopy. No break or duress was found over several impacts.

The 1/4 in. (6.4 mm) sheet appeared satisfactory, being sufficiently rugged for the mission time involved (a thicker sheet might be required for a permanent installation) and yet produce a negligible count loss. The 1/2 in. (13 mm) sheet produced a 6% loss in the count rate, which was deemed excessive for the purpose.

To verify the hypothesis that the steel canopy would produce the desired result of a near-vertical edge of the beam on the machine side, as shown in Figure 5, a test was also performed on the bed, with the sensor tilted 30 degrees from the vertical, with and without the canopy. The shale bed was covered with a strip of 1/2 in. (13 mm) of steel, simulating the edge of the roof shield on the longwall face, with the presumed edge of the beam grazing the steel edge (Figure 7). The sensor was raised and lowered over the bed, with the following results.

Height Over Bed		Counts per Second	
Inches	Centimeters	With Canopy	Without Canopy
3	7.5	—	265
6	15	241	263
9	23	242	256
12	30	238	251
15	37	232	245
18	45	225	238
21	54	220	234

• Trademark of the General Electric Company

Thus, the addition of the canopy reduced the 30-count variation observed without canopy to a 21-count variation, a 33% improvement in the error introduced by variable height of the roof over the sensor in the York Canyon configuration.

4.0 CALIBRATION PROCEDURE

For the display to provide direct read-out in inches of coal, the count rate has to be processed and linearized, with the count rate known for bare rock and assumed constant. Therefore, it is necessary to determine for each mine, perhaps for each face, what is the count rate from the roof rock, then set the electronic processing circuits accordingly.

Previous workers have reported that the radiation level of the rock material found above the coal is essentially constant; this finding was accepted with some misgiving, and attempts were made to correlate readings obtained from different locations. During the initial visit to the York Canyon Anderson machine, a sample of the roof rock was collected. After crushing and packing in a 2 in. (50 mm) deep aluminum box, this sample was presented to both the 5 in. (12.5 cm) sensor and the large-area sensor at the Marshall Flight Center facility. A similar sample from the Bruceton shale was also measured. Results were as follows.

	Large-Area Sensor		5 in. (12.5 cm) Sensor	
	Average	Sigma	Average	Sigma
York Canyon	97.4	10.1	99.04	10.2
Bruceton	119.5	10.6	123.4	9.6

This slight difference would produce an error in the coal thickness measurement; as a result, it was recognized that calibration would be required on the basis of the static tests made by observing bare rock in York Canyon.

A tripod was designed and built to allow positioning the sensor with respect to the face in the same orientation as the mounting on the shearer would subsequently determine. Figure 8 shows a sketch of the tripod used for the pre-testing in the mine.

5.0 TESTING AT THE YORK CANYON MINE

Arrangements were made to mount the natural background sensor system on the Anderson shearer at the York Canyon mine of Kaiser Steel Co. in Raton, New Mexico. An initial scouting trip in April 1980 indicated that indeed there was top coal left on the roof at the time; measurements of machine clearances also indicated that there would be enough room on the front of the shearer to mount the display box and battery box. Accordingly, an adjustable bracket was designed and fabricated for mounting the sensor, and a rack was also designed for mounting the display box, battery box, and Lockheed tape recorder.

Tests had to be scheduled at the convenience of the mine operator, and the first opportunity came in July 1980, with a team of two of the NASA personnel and two of the CRD personnel reporting at the mine portal during a maintenance shift period. During this period static measurements could be made on bare roof as well as arrangements for welding the necessary mounting pads for the bracket and rack assembly.

The first objective, making static measurements, was accomplished during the first night, and the results are reported below. Unfortunately, operating problems had arisen in the mining equipment during the previous shift, so that at the time the measurement team reported to the mine, no welder was available. This absence of welders persisted for two more days and, combined with the unexpected fact that the roof was competent enough for the mine operator to cut all the way to the rock, this situation led to the decision to pull the equipment back from the face and seek another location where the conditions would be more favorable. However, because no mine was immediately available as an alternate, a decision was made to return to the York Canyon mine at a time when operating conditions would have improved, with the hope that some coal would be left on the roof, even temporarily, to allow actual measurement during the cutting operations. This second trip was made in August 1980, when the sensor was successfully mounted on the shearer, as reported below.

5.1 Static Tests on Bare Rock - First Series

Six locations were selected along the face, two at the headgate and four near the shearer, with various amounts of coal left in spots, but no location was found where a positive condition of uniform top coal existed. Various distances between the sensor and the roof were used for these tests, as recorded on the notebook pages which are reproduced in part below, together with a sketch showing the relative positions. The actual data sheets are reproduced here for authenticity, and a summary is also compiled to provide the basis for conclusions. The data sheets are identified as Figures 9 through 13.

During these measurements, it became apparent that two radiation levels were present below the rock, depending on the rock formation. The interface between the coal and rock was more complex than the oversimplified concept of a simple interface. While the heavy rock layer above the coal was a white or light gray stone described as sandstone by mine personnel and classified as "graywacke" by a CRD geologist, thin occlusions of a darker gray rock could be observed from place to place but were not

readily recognizable under the lighting conditions and irregular surface of the roof. Samples were collected for measurement at the NASA facilities, using the crushed sample in a standard measurement cell developed by NASA.

5.1.1 Test Results

As indicated by the recordings of Figures 9-13, several radiation levels were observed, with difference even on bare rock measurements.

Location	Material on Roof	Counts in 10 seconds*	
		Lowest	Highest
1. (Headgate)	Rock - sandstone and shale	1638	1917
2. (Headgate)	Rock - sandstone and shale	1796	2040
3. (At shearer)	Rock - sandstone only	1243	1379
4. (At shearer) 27 in. (68 cm) from roof	About 6 in. (15 cm) of coal below unknown rock	1157	1221
5. (Near shearer) 18 or 24 in. (45 or 60 cm) from roof	Estimated 8 to 10 in. (20 to 25 cm) of top coal, uneven layers, below unknown rock	991	1079
6. (Near shearer) 23 or 29 in. (58 or 74 cm) from roof	About 2 in. (5 cm) of coal below unknown rock	1310	1416
7. At shearer	Bare rock, edge of shield in field of view	1907	1952
8. At shearer	Bare rock, moved sensor slightly to avoid shield	2023	2136

*Counts established by a digital counter developed by NASA and made available to the team during mine testing

Thus, it is apparent that two levels could be encountered on the roof, depending upon the thickness (if present at all) of the thin layer of gray "shale," which has a higher radiation level than the sandstone: a low range with an average around 1800 counts in 10 s, and a high range affected by the thickness of the occluded "shale" with one recorded average occurrence of 2050 counts in 10 s, a 14% difference in the "constant" rate that would be interpreted by the electronics as a 2 in. (5 cm) variation of coal thickness. As noted below, an even greater difference was observed during the second test series. Conceivably, the thin layer of "shale" might occasionally

become heavier, increasing the count rate further. That finding led to the initial decision to abandon the York Canyon mine because it did not appear to be a fruitful test mine. This decision was forced upon the team, in any case, during the available time period, for the operating problems of the mine prevented any attempt to mount the sensor bracket on the shearer.

5.2 Radiation Measurements on Rock Samples

Three samples were collected at the face for radiation measurement in the NASA standard cell: one sample of the light gray and dark gray shale-like material, and one sample of the white sandstone-like material. These samples were classified by a CRD geologist as follows:

- White "sandstone" graywacke (sandstone)
- Light gray "shale" siltstone
- Dark gray "shale" silty shale

Radiation measurements made at NASA on these samples showed that the sandstone was less than half of the other shales.

5.3 Static Measurements on Bare Rock - Second Series

Following a decision to attempt a second time to make measurements at York Canyon, primarily because no other mine had been identified at the time and because of the potential benefit of obtaining operating experience under cutting conditions, even if in a less than ideal mine, a second test series was undertaken.

Two locations were selected for making the static measurements, the first at the last open cross-cut of the entry, near the head gate, where the visible rock is described as "shale" on the NASA team notebook (Figure 14). The second location was with the sensor already mounted on the shearer, which was parked at the headgate on the first night. The first measurement was made without and with the canopy on the sensor, identified as "window shield" in Figure 14. The results show again the existence of two radiation levels, both of them higher than those observed during the first test series, although no change had been made in the sensor system between the test series.

The counts reported here were obtained by a direct output from the sensor amplifier, brought out to the output connector of the display box and thence to a special counting circuit developed by Messrs. Crouch and Rose of NASA. Thus, the calibration procedure, described in Appendix A, does not affect the count results.

On the other hand, the output of the display intended for tape recording of "inches of coal," or for driving the light-emitting diode (LED) display on the box, is dependent upon the calibration, which in turn is based on the foreknowledge of the bare rock count rate. Conversely, if a valid set of recordings is made of the apparent coal thickness for an arbitrary calibration and these are correlated with the measured (physically) coal thickness, it is possible to derive graphically an *a posteriori* calibration. At the point reached in the night schedule, and with the finding of the variable level

of radiation prevailing on the site, the decision was made not to change the calibration of the signal processing circuitry but to leave it at the value set during the previous trip to York Canyon, i.e., the low count range observed during that series. The plan was to follow later with either an *a posteriori* calibration or to perform a new calibration that would match the prevailing count rate at the location where measurements could be made along the face. As will be discussed in detail below, the roof height conditions were such that the tape recorder could not clear in some areas; the plan, therefore, was to install the recorder at the last minute at some favorable location, make the measurements, and remove the recorder before the shearer would advance to the area of low roof.

At that point also, it has become apparent that the roof conditions were allowing the operators to remove all the coal, leaving the bare rock exposed. In most locations examined during the maintenance shift, it seemed that the roof surface had not been scored by the picks, but rather that the upper layers of the material removed in the path of the shearer were actually falling from the roof, leaving a "natural" interface boundary on the roof. Thus, there would be ample opportunity to make bare rock measurements along the face while the shearer operated. A request to the mine operators to try lowering the ranging arm for a short pass was accepted, so expectations of making measurements on a true top coal layer set the stage for the following day, when operating measurements would be made.

5.4 Dynamic Measurements During Operation – First Day

With the instruments mounted on the front of the shearer (Figure 15) and the sensor on the face side of the shearer (Figure 16), the team awaited the first operation of coal cutting to make the recordings. There would be no opportunity during this first shift to measure the coal thickness: there was very little top coal in the first place, and no interruption of the operation long enough to make physical measurement would be allowed. The intent was to collect a backup set of measurements immediately upon the beginning of the cutting operation, should the system fail to survive two shifts. The prime measurements were intended to be made in the last hour of the second shift, prior to the cutting operations being shut down for the third maintenance shift, during which physical measurements could be made.

A reel of tape was therefore brought out of the mine, containing a few feet of recording made while the shearer was moving along the face and the sensor looking at essentially bare rock. However, as mentioned above, the mine operators had been sympathetic to a request for leaving some top coal during the second pass of measurements, scheduled for the end of the second shift.

The tape was then played and recorded on a strip chart at the "base" motel, with the disappointing finding that nonsensical outputs had been recorded: a trace at some variable level with full-scale fluctuations. Electrical interference by the machine or an intermittent contact in the tape recorder were conjectured to be the cause.

At this point, it is necessary, both for the sake of objectivity and as a forewarning to other potential users of this tape recorder, to note the difficulty encountered in starting the tape recorder under the pressure of "minimum interruption" modus

operandi. As a result of the revised Mine Safety and Health Administration (MSHA) requirements for accepting the recorder as intrinsically safe, an elaborate circuitry had been devised for starting the recorder, which resulted in only a fraction of the attempts to start it being successful: the tape would begin to move, but the safety circuitry would cause an abort and the reels would coast to a stop, leaving slack in the tape. The next attempt to start might be successful, so that the team would be under the false impression that all was well. An additional problem was that the construction of the tape recorder lid would not allow a quick closing of the lid. To allow access to the control buttons without opening the lid, a window with a sliding cover was cut in the lid, thus gaining precious minutes in the interruption required from coal cutting each time the recorder was started or stopped.

However, this scheme also prevented full view of the capstan drive of the tape, and this is what caused the nonsensical recording of the first recorded pass: during one of the aborted starts of the recorder, or even during a single start following inspection of the tape and closure of the lid, the slack in the tape, taken up with a snap as the takeup reel moved, caused the tape to jump out of the takeup capstan. The recorder, an FM type, experienced unstable recording speed with the tape disengaged from the capstan, producing the wide amplitude variations on the demodulated output. The first recording series, as a result, was a total loss. This situation was not recognized until the team adjourned to the motel following the first pass of recording. Fortunately, however, the failure was identified before the second day of measurements, and precautions were taken against this occurrence.

5.5 Dynamic Measurements During Operation – Second Pass

The team reported at the mine portal toward the end of the second shift, slightly ahead of schedule, to be greeted with the news that the shearer would be in the tail gate area, where the roof height seemed optimum (or perhaps least undesirable) for the contemplated measurements with attempts to leave top coal. With due caution on startup, a rush was made to install the tape recorder on the shearer and to proceed with the measurements.

One positive result was immediately apparent: upon startup all circuitry functions appeared operational, thus demonstrating the capability of the mechanical and electronic components to survive the mine environment. This finding contrasted with that of previous experiences on other projects quoted by NASA, where components had not survived the shearer operation very long.

Thus the measurement series started with very little preparation possible or required, since all seemed in order and the operators were understandably eager to resume cutting coal after the interruption, brief as it was, required to lash and connect the tape recorder.

As agreed, the shearer crew attempted to leave top coal by lowering the drum while the shearer was advancing. However, because the previous pass had exposed the rock, and the coal left by the lowered drum was not supported on the shield side, practically all of the 10 to 12 in. (25 to 30 cm) left uncut would fall from the roof, leaving essentially bare rock in view. In a few locations, some coal was left at the

corner of the roof-face junction, raising the possibility of collecting top coal data during this pass, albeit not on a uniform top coal layer.

As the shearer proceeded toward the headgate, with the recorder operational, comments from visual observation of the roof conditions were entered in the team notebook, the location of the hydraulic jack was recorded, and voice comments were entered on the voice channel of the recorder as planned. The objectives of the test series seemed indeed about to be accomplished when the face conveyor broke down after only minutes of recording. Damage to the conveyor was such that operations were shut down for the remainder of the second shift.

Later, at the portal, the few minutes of recording were played back on the strip chart recorder. Both channels, the direct count and the "inches of coal," were clean and free from the interference noted in the first series, but a peculiar pattern of rapid collapse to low coal thickness (high count rate) was observed. Figure 17 shows the strip chart playback of the tape, as played back in the laboratory (the playback made at the portal was left with the shift superintendent as a goodwill gesture). This figure includes the transcript of the voice comments and notebook entries, and thus represents the expected yield of the test series, at least in principle.

The recordings seemed to indicate a very high count, expected since bare rock was being scanned most of the time, with occasional rises in indicated inches of coal. However, a disturbing fact was that the collapse to "bare rock" and subsequent rise seemed to coincide with the start and the stop of the shearer, respectively. Calibration and bare rock outputs recorded while the shearer was stopped indicated normal behavior. The team had to make an instant decision on how to proceed. (See the details of Figure 17).

Inputs to the decision-making process were the following:

1. The roof conditions were such that there was little probability of recording a clean top coal condition. Attempts by mine operators to leave top coal had failed, and the team had been specifically directed to cause as little disturbance as possible in the operational routines; better yet, none.
2. The breakdown of the conveyor seemed serious; on the basis of the experience of the first trip, where similar problems in the mine equipment resulted in three days of waiting without a chance to resume measurements, it seemed that the likelihood of taking further measurements in the next few days would be slim.
3. From the observed variable radiation prevailing along the roof, it seemed that any further recordings made, if any, would be controversial, since conclusive evidence had been obtained that the fundamental assumption associated with the system, i.e., constant radiation level, was not true for this mine.

4. One of the major objectives of the trip, demonstrating that the sensor hardware and software could survive the environment and collect data, had been attained.

Based on these facts, the joint decision of NASA and CRD was to terminate the tests and remove the equipment from the shearer. As the third shift was now in progress, it was possible to do so instantly, thus minimizing further nuisance to the mine operators. The team therefore returned to the face to remove the equipment and to make formal observations of the roof conditions that might correlate with the observations of variable radiation recorded in Figure 17.

Indeed, close examination of the interface area between the roof and the vertical face showed the occurrence in some spots of a variable layer of the darker gray rock, previously identified as siltstone, while at others there seemed to be a direct interface between the sandstone and the coal. This finding reinforced the hypothesis, without completely verifying it, that the fluctuations in the recordings might have been caused by scanning variable radiation areas. In any case, this finding reinforced the conclusion that the natural background sensor approach would not be successful for the conditions existing at York Canyon.

Thus, the test series at York Canyon were terminated with the conclusion that operational ruggedness had been successfully demonstrated, that some mines might not be suitable for the natural sensor background system, and also that the puzzling recording pattern warranted some further investigation. This last item is now reported.

5.6 Susceptibility of the System to Electromagnetic Interference

As an alternate hypothesis to variable radiation levels causing the fluctuations recorded in Figure 17, the possibility of electromagnetic interference with the electronics was also considered, and was investigated in the laboratory. Two mechanisms were considered: (1) a 60 Hz interference that would be produced by the magnetic field of the shearer motor, and (2) a high-frequency interference that might be caused by switching or other function of the shearer controls.

Close scrutiny of the equipment built and furnished by NASA disclosed that the mechanical connection of the cable connecting the sensor to the display box did not provide a continuous shield; rather, the "common" connection was effected by one of the wires in the cable (Condition 1 in Figure 18). Therefore, any magnetic field created by the shearer motor could link the loop established by the sensor box, the common wire, the display box, and the frame of the machine (Figure 19). Such a magnetic flux could induce a circulating current in that loop. This flux (Φ) can be simulated by forcing a current into the loop with a current transformer, as shown in Figure 18, Condition 1.

The other possibility of a high-frequency interference was first conjectured with the hypothesis that some high frequency might be generated by the motors or control system of the shearer. Such an interference can be simulated by a test in accordance with IEEE Standard C37.90a-1974, "Surge Withstand Capability" (SWC), generating a 1 MHz burst at a 60 Hz repetition rate.

While attempts were made to obtain information on the circuitry in the Anderson machine from its manufacturer (it took several weeks to contact the appropriate person), both 60 Hz circulating current tests and SWC-type tests were performed. Both produced effects very similar to that observable in Figure 17. Hindsight acquired by that time made Condition 1 of Figure 18 a likely candidate for this type of interference: the circulating current forced to flow in the common wire of the harness induces a voltage drop which the electronics misconstrue as a pulse count.

Figure 19 shows the recordings obtained from the sensor systems looking at the laboratory shale bed, with injection of circulating current as shown in Figure 18 at various levels, marked on the upper part of the chart. The shield was open-circuited, corresponding to Condition 1, the condition existing at York Canyon. This chart shows that in the vicinity of 1 A of circulating current, the system is driven to the same condition observed during operation of the shearer. Figure 20 shows recordings made with a digital storage oscilloscope: at 0.9 A the random pattern of counts produced by the sensor photomultiplier is apparent. At 1.2 A, at the same time of the 60 Hz induced voltage visible on the 40 ms window picture, a burst appears, shown expanded in the picture on the right. At 1.5 A the burst is so wide that the zero line trace is actually broken by the solid occurrence of multiple false pulses induced in the system. The shield was then made continuous by tying points S1 and S2 (Figure 18, Condition 2). A third condition, (3), was also produced by opening the connection existing between the common point and the sensor case.

With either of these conditions, the 60 Hz current injection produced the results shown on Figure 21. With Condition 2, the threshold of interference, which was 1 A at York Canyon, is raised to 15 A. With Condition 3, the threshold could not be reached at 30 A.

Figure 22 shows a similar pattern of increasing threshold of interference during a test where a SWC generator was feeding a loop of wire running along, but not contacting, the cable connecting the sensor to the display box. Under Condition 1, and occasionally under Condition 2, the system could be driven out of control. No interference could be produced with the shield and common configuration of Condition 3.

Based on these findings, the conclusion was reached that the erratic recordings made in York Canyon (Figure 17) were most likely caused by an induced 60 Hz current flowing in the wiring loop. Naturally, both systems were immediately modified to provide the continuous shield and common separation in the sensor corresponding to Condition 3.

6.0 FURTHER COLLIMATION

With the experience gained during the test series, increased awareness of the need for tight collimation led to modification of the sensor canopy by inserting a "well" made of 1/2 in. (13 mm) steel plate, 4 in. (10 cm) deep, into the window of the canopy. This extension of the existing well provided by the lead casting in the sensor case was expected to produce a tighter collimation, enabling the sensor to view a smaller area, hence to be located farther from the roof and to allow roof height variations with lesser variations in the collected radiation. Figure 23 shows the count rate observed in the laboratory, with and without the additional collimating well, with the sensor looking at the shale bed and a 1 in. (2.5 cm) steel plate being moved from the fringe of the field into the sensor field. While the count rate was reduced by the addition of the collimating well, the onset of the slope occurs closer to the canopy edge than without the well, demonstrating the reduced beam angle. This additional well was delivered to NASA during the initial measurements at the Old Ben mine, in preparation for a second mine tests series. However, this second test series at Old Ben was not made under the subject contract, but independently by other NASA personnel.

7.0 CONCLUSIONS AND RECOMMENDATIONS

1. The experience gained in the three visits to the York Canyon mine and three scouting visits to other mines shows that geological conditions are such that the constant or near-constant radiation level, which is the underlying assumption of the natural background sensor approach, should not be expected blindly.
2. The hardware developed by NASA and the installation hardware developed by CRD were both adequate to survive the mine environment, and the electronics performed satisfactorily, with the exception of a susceptibility to 60 Hz interference. However, that susceptibility was identified and corrected.
3. Tight clearances around the shearer make it highly desirable to reconsider the total package:
 - a. The visual display should be separated from the rest of the system to allow mounting in a very small box near the machine controls. This separation would allow the present display box, or a redesigned box of smaller dimensions, to be mounted out of the way, elsewhere on the shearer.
 - b. The digital meter is useful for laboratory calibrations but not during measurements in the mine. A mine-dedicated system would be better without the added circuitry.
 - c. A more compact tape recorder, with a reliable start, is needed for further work. The last thing that a team needs, under the pressure of work done under a directive of "minimum interruption of coal cutting," is a temperamental tape recorder.

ACKNOWLEDGMENTS

The author wishes to acknowledge the contribution, assistance and advice of Messrs. Leet of GE CRD, for laboratory and mine calibration and measurements; Rose and Crouch of NASA, for the team effort during mine testing, with due recognition for the initial circuit development; Pazuchanics of the Pittsburgh Mining Technology Center, for arrangements in Bruceton; and McConnell of CRD, for identifying the rock samples.

APPENDIX A

CALIBRATION PROCEDURE

I. Calibration of Detector AMP

- Step 1 - Apply 13 V to Pin 14 +13 V, checking to see that regulator has +8 V at pin 21.
- Step 2 - Set R8 (zero) so output of IC-3 (Amp 1) is +600 mV (DC).
- Step 3 - Set R16 (zero) so output of IC-4 (Amp-2) is +10 mV (DC).
- Step 4 - Set R15 (gain) of IC-4 mid-range.
- Step 5 - Set R22 (zero) so output of I2-5 is +10 mV (DC).
- Step 6 - Set R27 (zero) so output of IC-6 is +10 mV (DC).
- Step 7 - Set R29 (discriminator) so Wiper is \approx +1 V (DC).

II. Signal Process Calibration

- Step 1 - Turn on, put in calibration mode.
- Step 2 - Set R21 (2nd discriminator) fully clockwise and R16 and R25 (first and second gains) fully clockwise.
- Step 3 - Put a counter on discriminator signal and set front panel calibration potentiometer (cal. pot.) for rock count (no coal). Set R30 (main gain) to mid range (12 turns from either end).
- Step 4 - With D.V.M. looking at wiper of R4, set R4 for 200 mV.
- Step 5 - With D.V.M. on recorder output to tape recorder, adjust R10 (first discriminator) clockwise until there is a reading of 0 V (0.1 V to 0.2 V). Then turn counterclockwise slowly until reading just starts to increase and set R10 just clockwise from that threshold.
- Step 6 - Then set cal. pot. for counts at 4 in. coal from *your* calibration graph., set R16 counterclockwise for 0.5 V per 1 in. coal (2 V for 4 in. coal).
- Step 7 - Check calibration by doing steps 5 and 6 again, then compare to *your* graph.
- Step 8 - Set cal. pot. for counts at the breakpoint of the two slopes from your calibration graph. Turn R21 counterclockwise slowly until voltage just increases, then turn back clockwise to just below that threshold.

- Step 9 - Set cal. pot. for counts for 10 in. coal and adjust R25 counterclockwise for 0.5 V per 1 in. coal (5 V).**
- Step 10 - Recheck steps 8 and 9 again and check complete calibration from 0 in. coal to 10 in. coal.**

III. Coal Depth Meter Calibration on Signal Process Board

- Step 1 - Set cal. pot. for any even value of voltage at the recorder output. If set for 5 V [at 10 in. coal], adjust R33 for a reading of 10.00 V on front panel meter.**

IV. To Set Error Display (L.E.D.)

- Step 1 - Adjust cal. pot counterclockwise down to 50 counts (on discriminator signal). Adjust R34 counterclockwise (If L.E.D. is off) to point where light just comes on. If L.E.D. is already on, adjust R34 counterclockwise until light just turns off.**

V. Display Card Calibration

Still in calibration mode, set low battery voltage light.

- Step 1 - With D.V.M. on wiper of R4, set R4 for 3.7 V then check by adjusting (13 V) power supply down to around 11.2 V, and light should come on. If not, adjust clockwise until it just comes on.**
- Step 2 - Set R13 to mid range (12 turns from either end)**

VI. Calibration of L.E.D. Depth Display

This must be done according to the desired coal depth to remain on ceiling. Once a depth has been decided, for instance, 4 in. coal, then, still in calibration mode:

- Step 1 - Set cal. pot. for a reading of 3 in. on display. Adjust R34 clockwise until down arrow just comes on (from upper yellow state).**

- Step 2 - Set cal. pot. for 3.5 in. on display and adjust R31 clockwise so upper yellow light just comes on (from green).**
- Step 3 - Set cal. pot. for 4.5 in. on display and adjust R28 counterclockwise until lower yellow light just comes on (from green).**
- Step 4 - Set cal. pot. for 5.0 in. on display and adjust R25 counterclockwise until up arrow just comes on (from lower yellow).**

Recalibration to another desired coal depth must be done in the order above, but settings on either side of the desired depth can be positioned where desired.

APPENDIX B

RECOMMENDED PROCEDURES FOR INITIAL AND PERIODIC CHARGING OF NBS BATTERY PACK

I. Completely Discharged Batteries

- Battery assemblies are shipped totally discharged
- Refer to drawing nos. 50M28101 and 50M28102
- Battery recharging current passes through the 185 current limiting resistor

- Step 1 - Select a charger power supply with adjustable output voltage and current. Limit the current from the power supply to 0.5 A and adjust output voltage to zero.
- Step 2 - Connect the battery plus (red wire) pins E and F to the positive output of the power supply and the battery negative (black wire) pins A and C to the power supply negative.
- Step 3 - Slowly increase the voltage to 10 V and watch the output current. When the current has dropped to 50 mA proceed to step 4.
- Step 4 - Slowly increase the voltage to 15 V. When the output current has dropped to 50 mA proceed to step 5.
- Step 5 - Slowly increase the voltage to 20 V. When the current falls to 100 mA, readjust supply output to 30 V and set current limit at 0.4 A.
- Step 6 - Charge the battery at the constant current for approximately 13 hours.
- Step 7 - Reduce the supply voltage to 22 V and allow battery to trickle charge until fully charged (about 3 hours).

II. Periodic Recharging

- Do not allow batteries to discharge below 1 V per cell.
- Keep track of the battery current load and elapsed time of usage so that the charge put back into the battery can be regulated to the amount removed plus 10%.

- Step 1 - Select a charger power supply with an adjustable output voltage and current. Limit the current to 0.4 A and set the output voltage to 30 V.**
- Step 2 - Connect the battery plus to the supply plus and the battery negative to the supply negative.**
- Step 3 - Allow the battery to recharge to the amount of energy removed plus 10% or until battery voltage is approximately 22 V.**
- Step 4 - When the battery is about fully charged, drop voltage to 22 V and trickle charge limiting input current to 50 mA.**

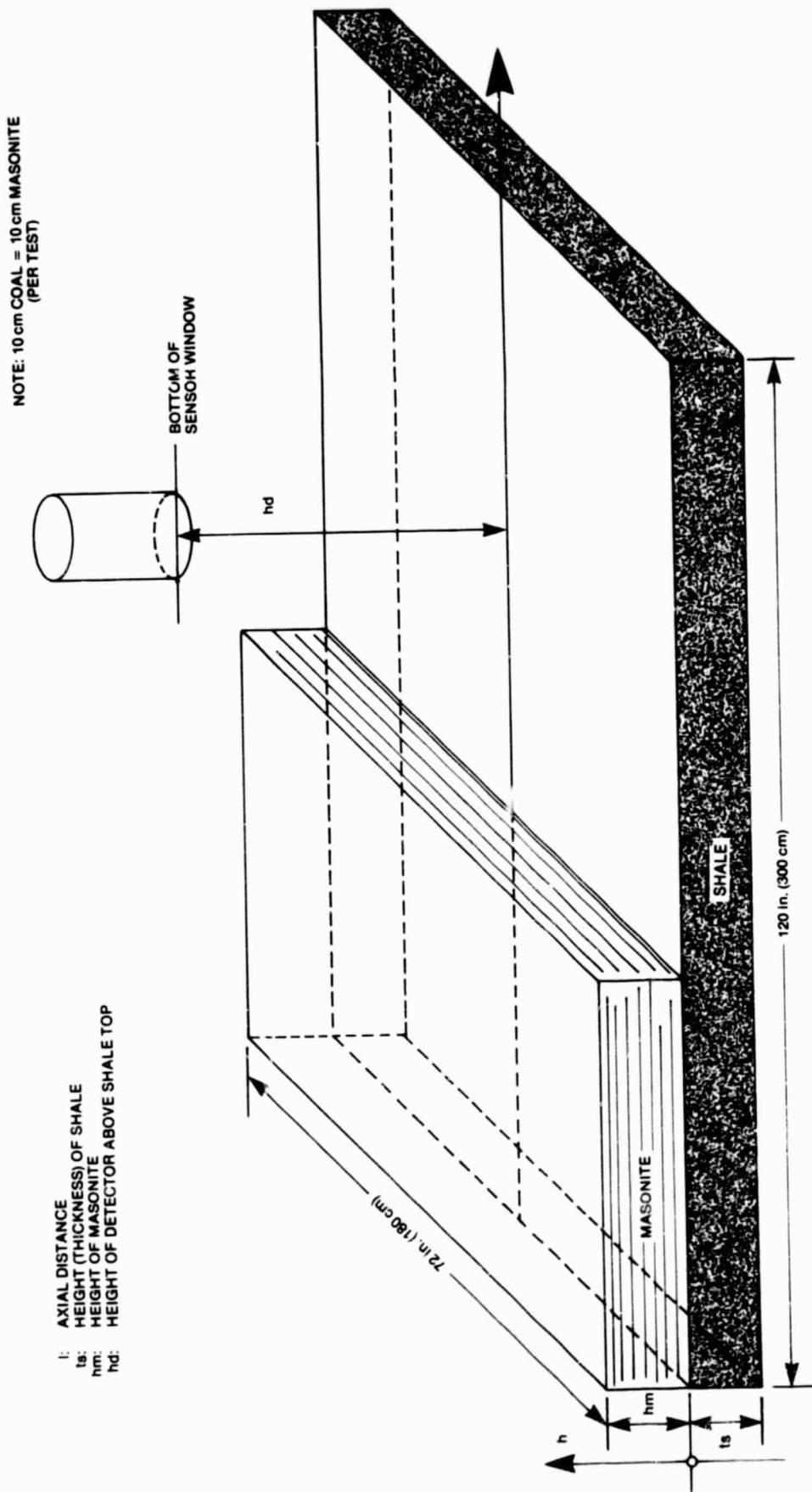


Figure 1. Dimensions of test bed

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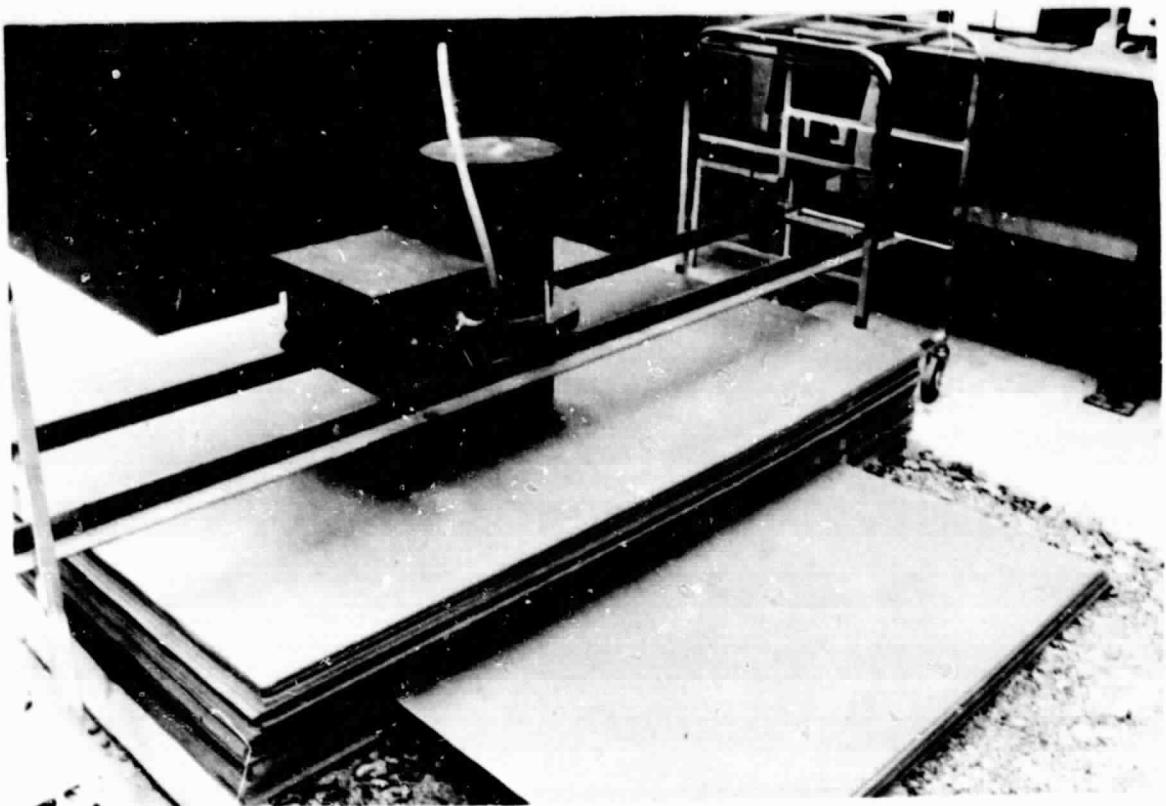


Figure 2. Laboratory arrangement for natural-background sensor testing

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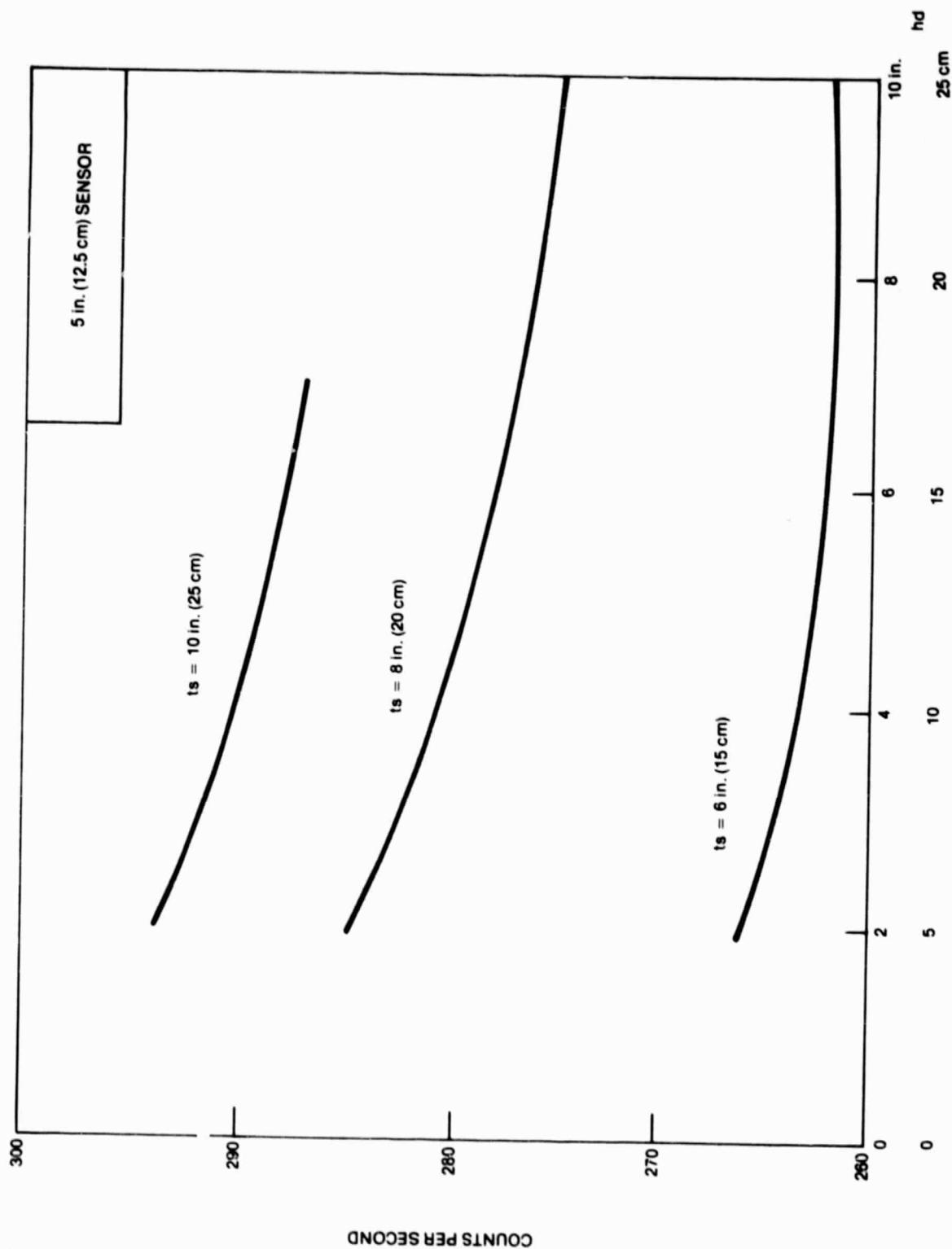


Figure 3. Count rate vs. shale thickness and vertical distance

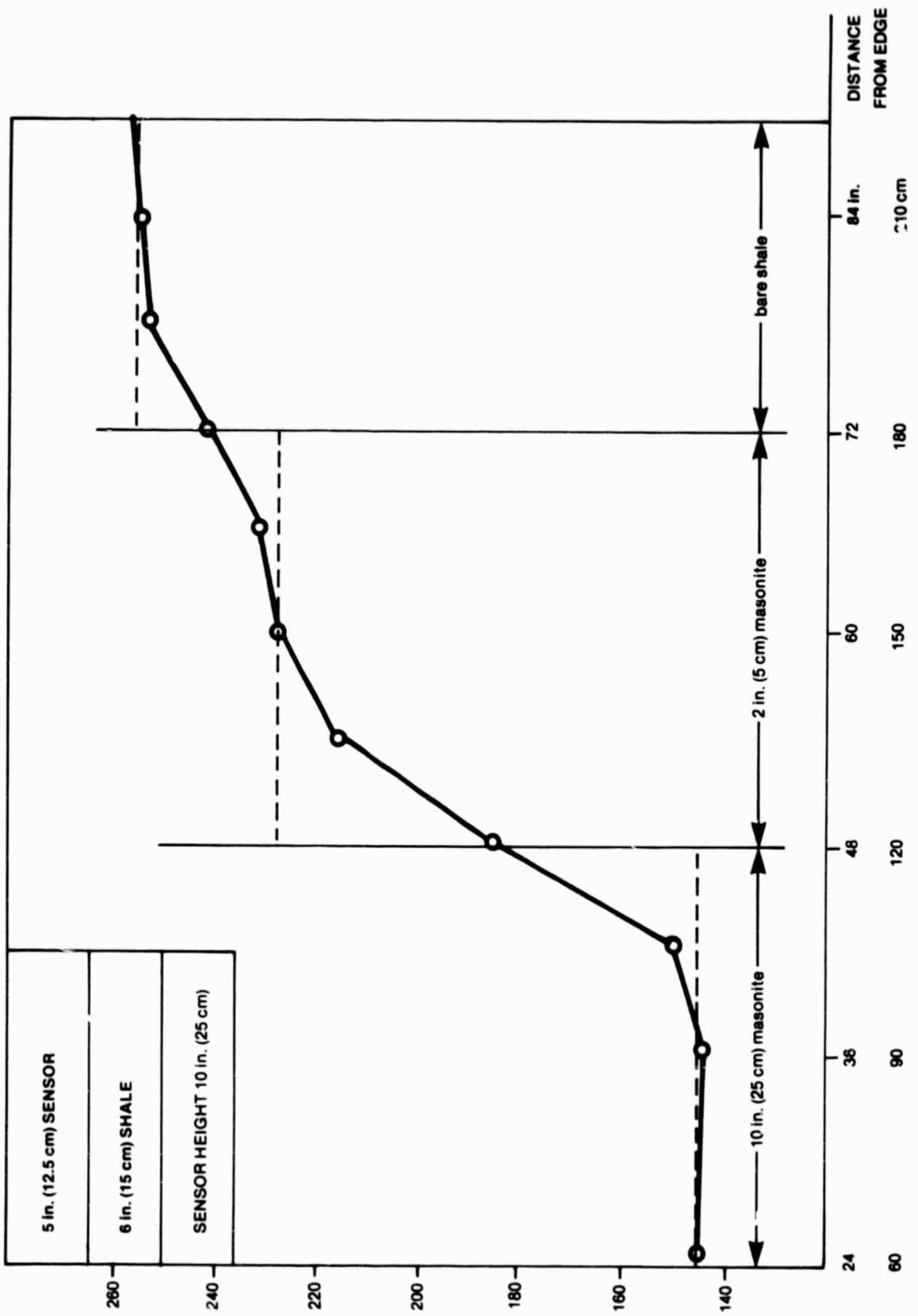


Figure 4. Response to step changes in "coal" thickness

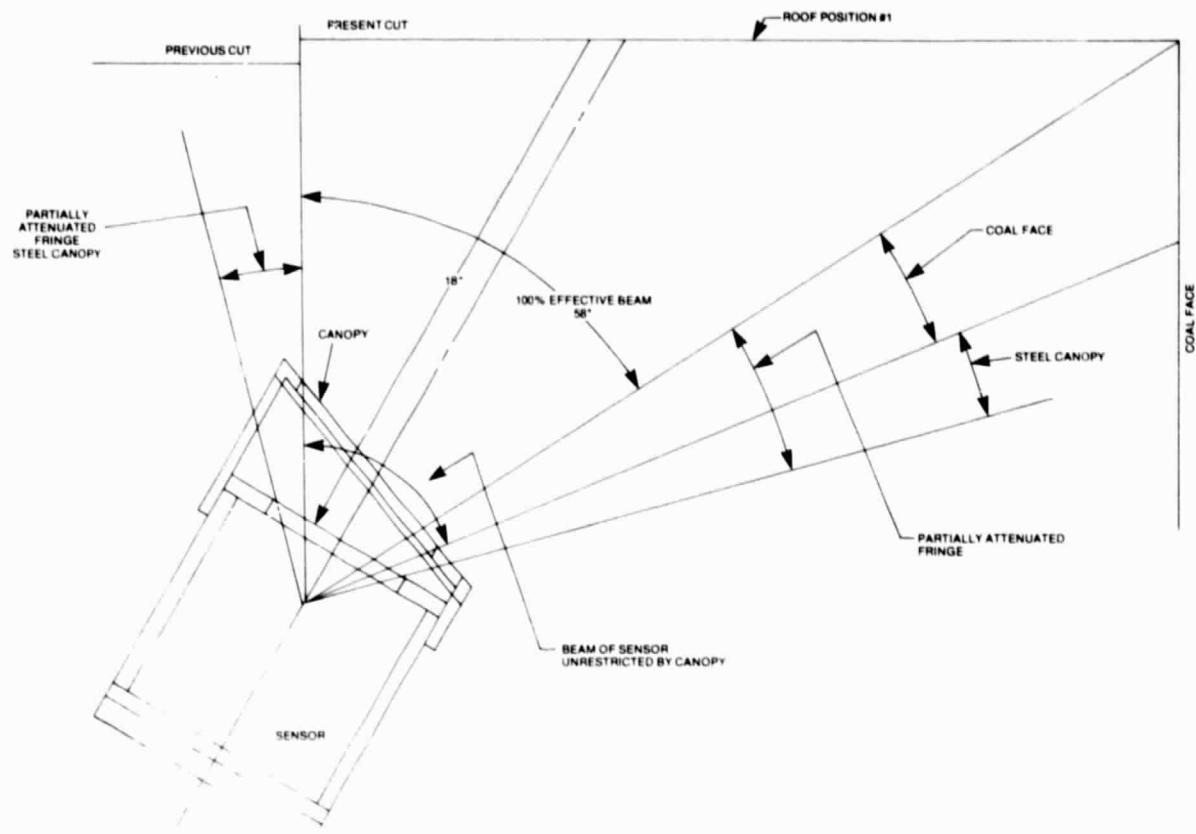


Figure 5. Relative position of sensor at the York Canyon face

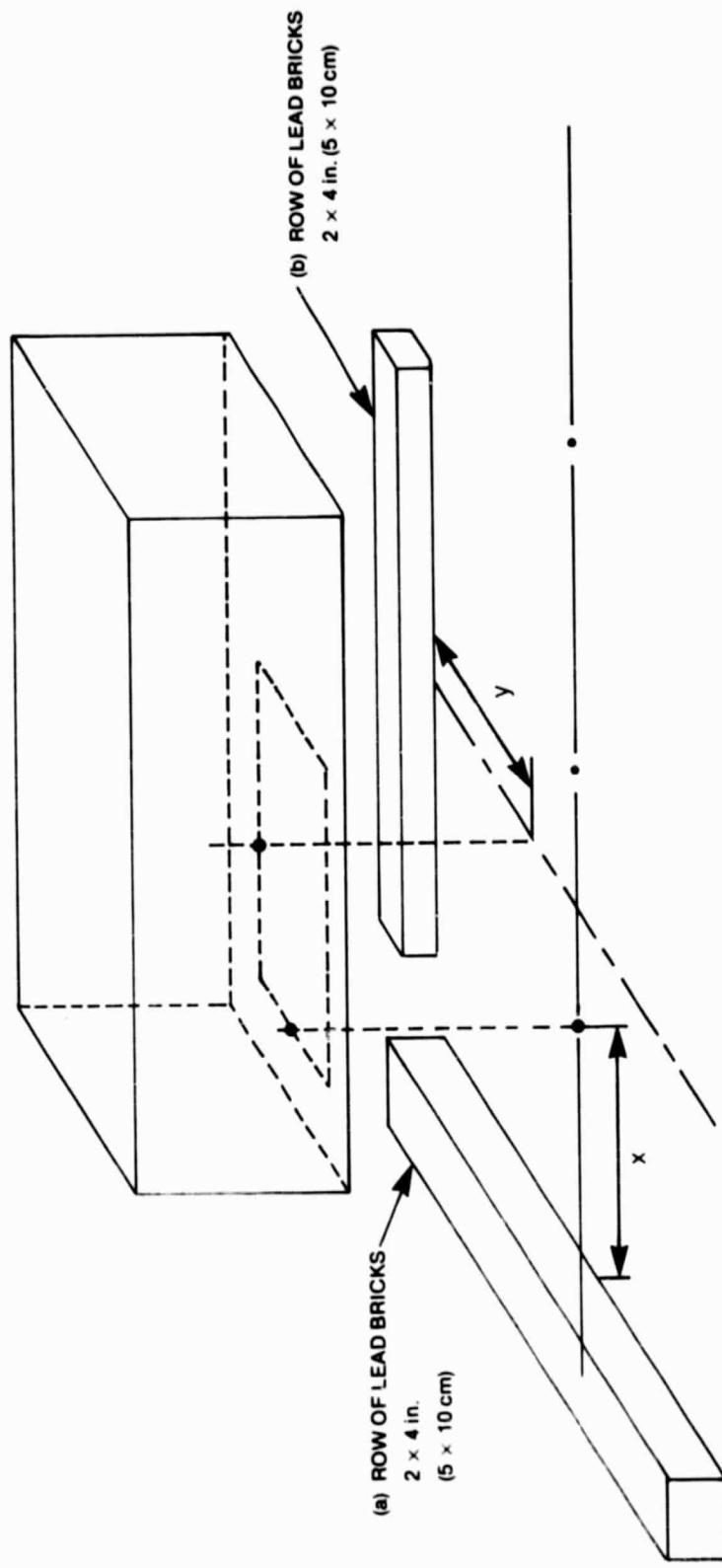


Figure 6. Determination of beam edge

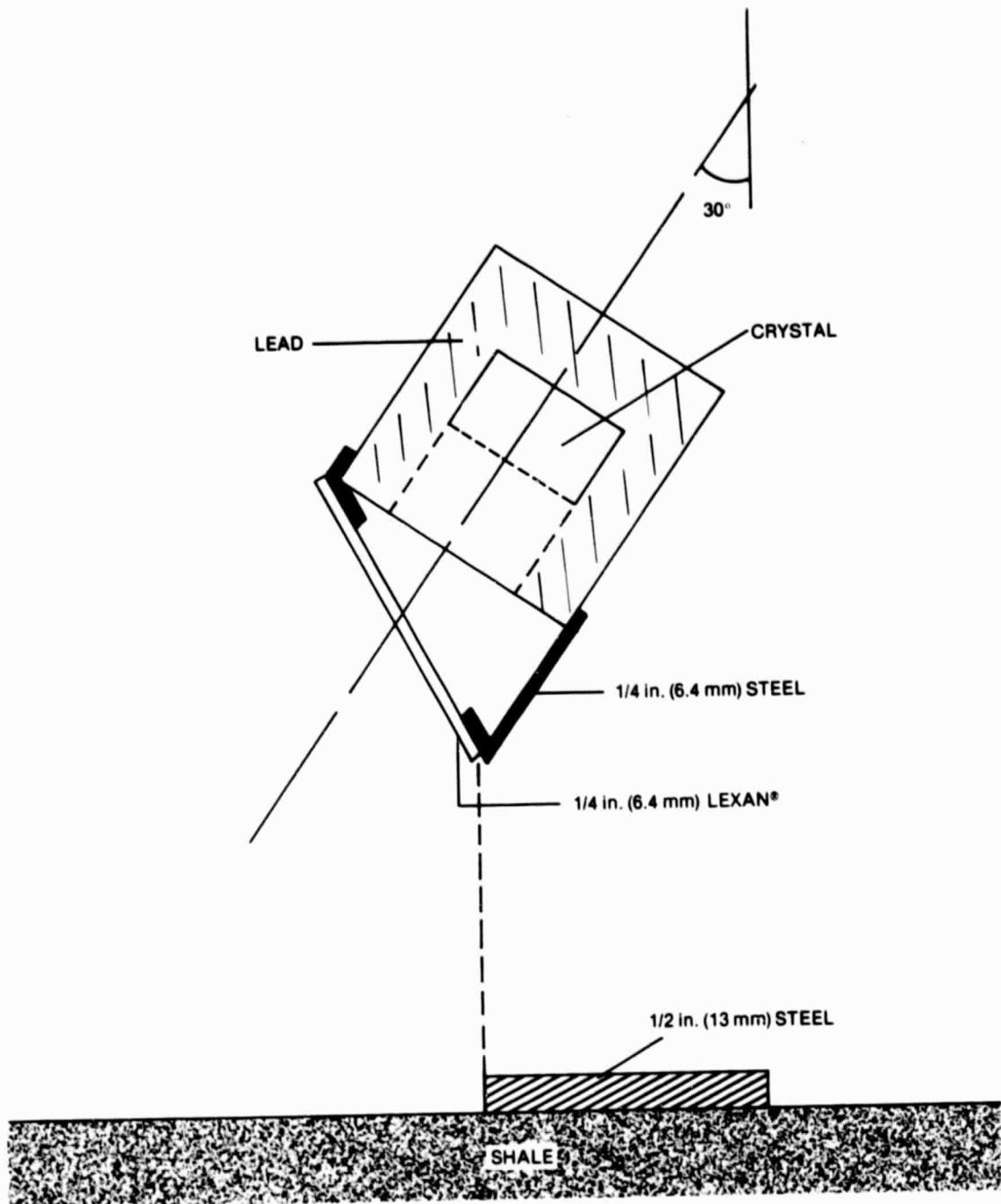


Figure 7. Restriction of beam angle by canopy

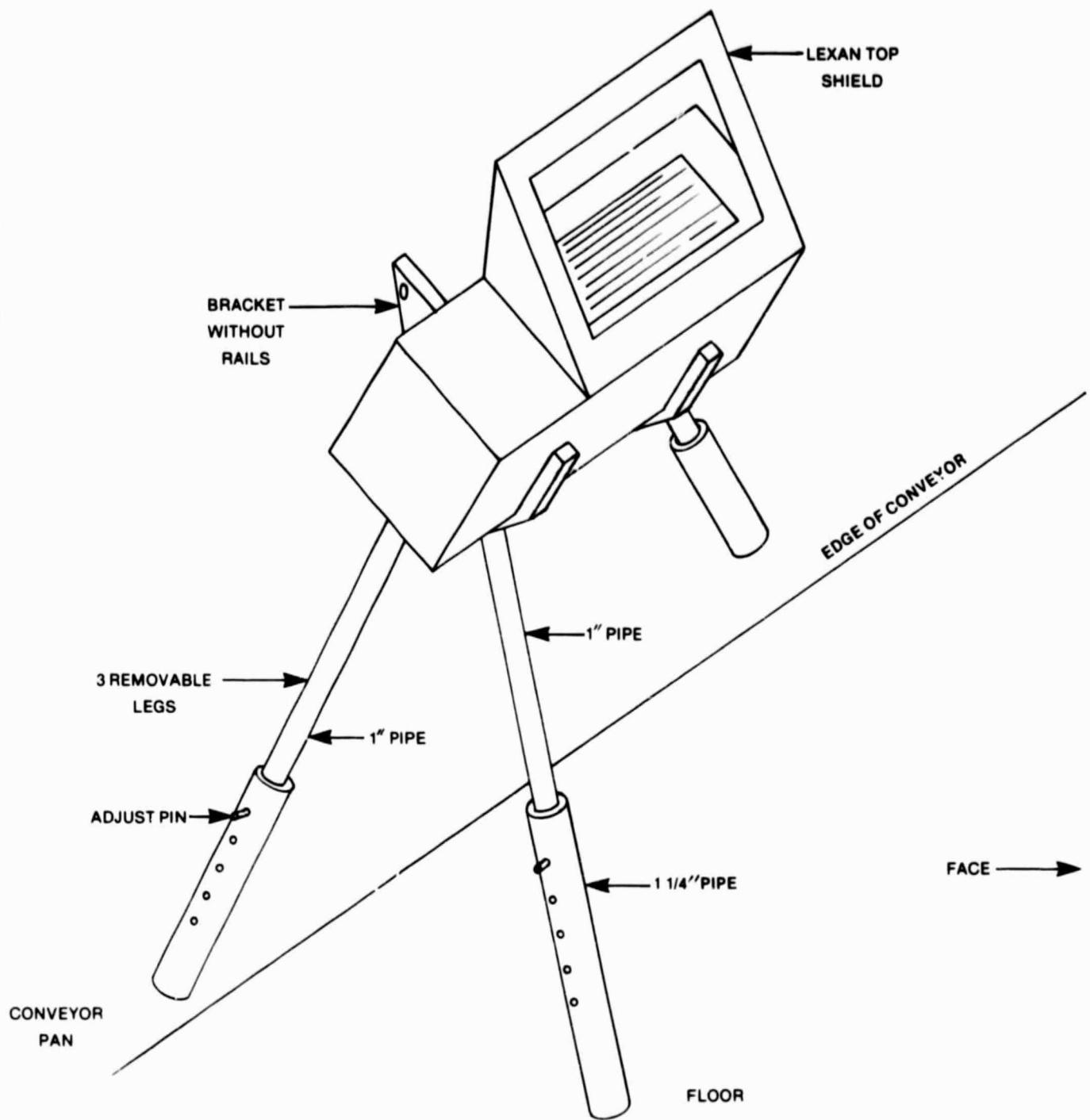
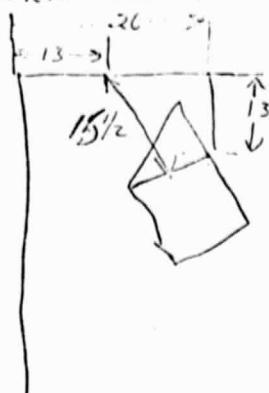


Figure 8. Tripod for static tests

7-28-80

YORK CANYON

A



CALIBRATION Location 1 (AFTER
ANTE)

10 SEC

16 38

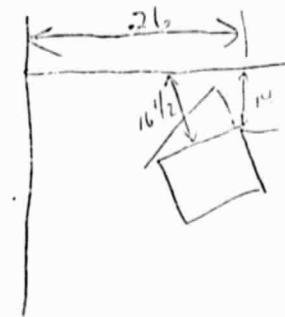
17 22

17 13

16 80

$16 88.25 \pm 38.1$

B



10 SEC

10 SEC

17 67

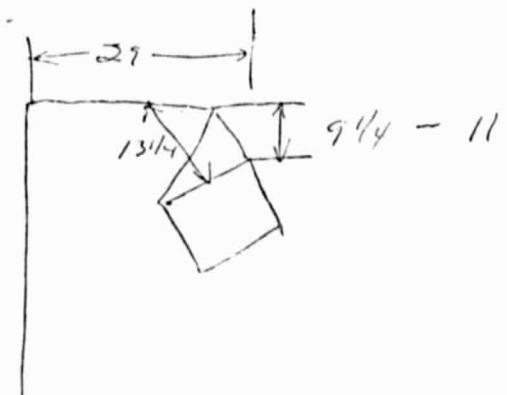
18 07

18 93

19 17

$18 46 \pm 70$

C



9 1/4 - 11

10 SEC

18 66

17 96

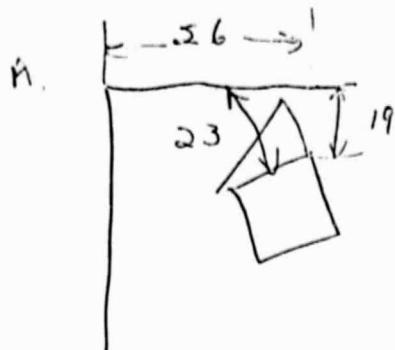
18 07

18 06

$18 18.75 \pm 31.9$

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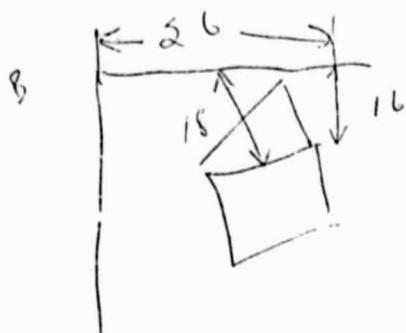
Figure 9. Notebook entries of York Canyon tests



Location 2 HEAD GAGE

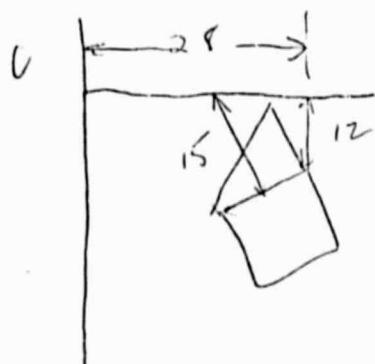
10 SEC

$$\begin{array}{r}
 1838 \\
 1796 \\
 1886 \\
 1875 \\
 \hline
 1834.25 \pm 67.4
 \end{array}$$



10 SEC

$$\begin{array}{r}
 1915 \\
 1838 \\
 1876 \\
 1881 \\
 \hline
 1873.53 \pm 31.5
 \end{array}$$



approx 1 1/2 core? Probably rock

$$\begin{array}{r}
 2040 \\
 1908 \\
 1974 \\
 1978 \\
 \hline
 \end{array}$$

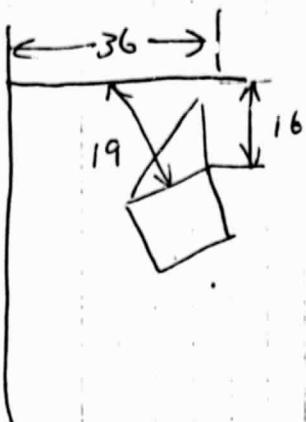
$$1960.75 \pm 61.3$$

Figure 10. Notebook entries of York Canyon tests

LOCATION 3

at shear drum position

3



10 SEC

12 13

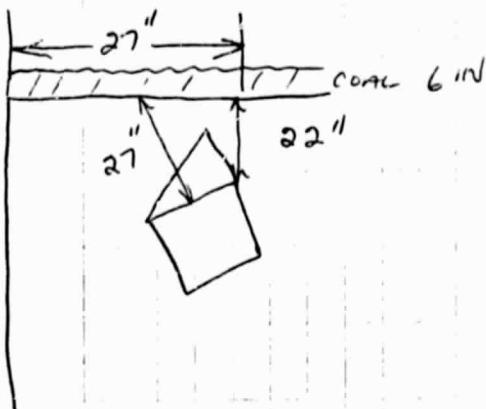
13 79

12 98

12 98

1304.5 \pm 56.0

7-29-80 YORK CANYON
Loc. 4 More coal left on roof



10 SEC

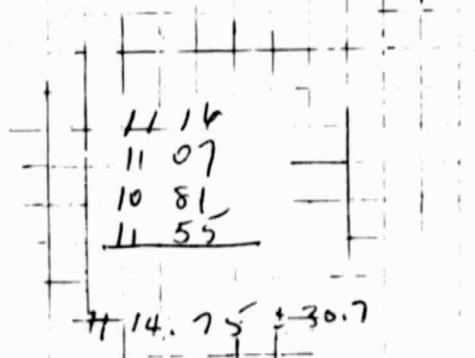
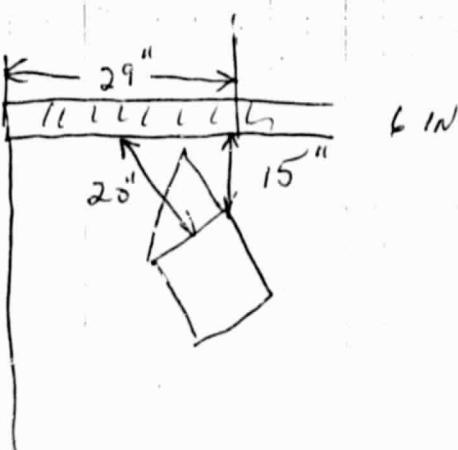
12 08

12 21

12 06

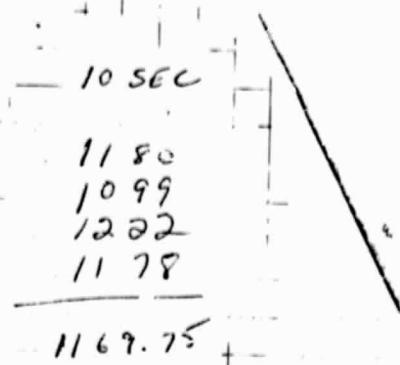
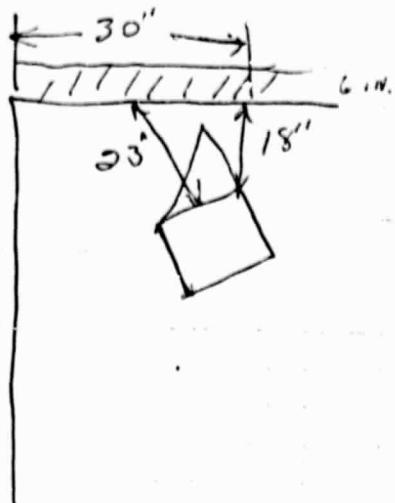
11 57

11 98 \pm 28.1

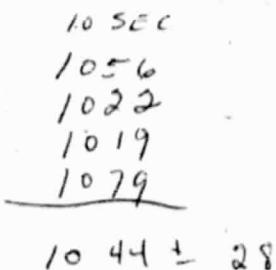
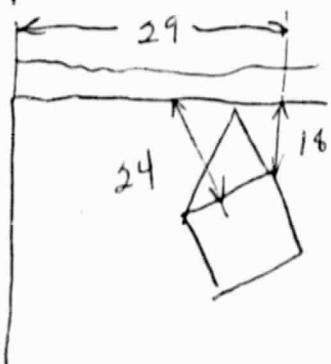
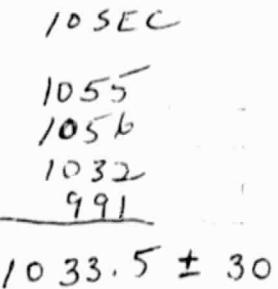
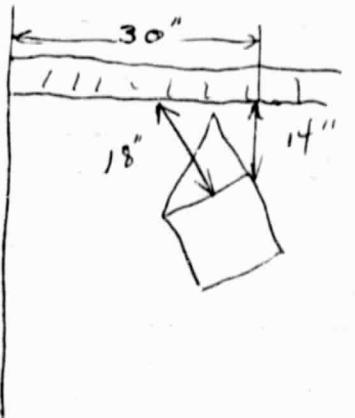


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Figure 11. Notebook entries of York Canyon tests



LOCATION 5



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Figure 12. Notebook entries of York Canyon tests

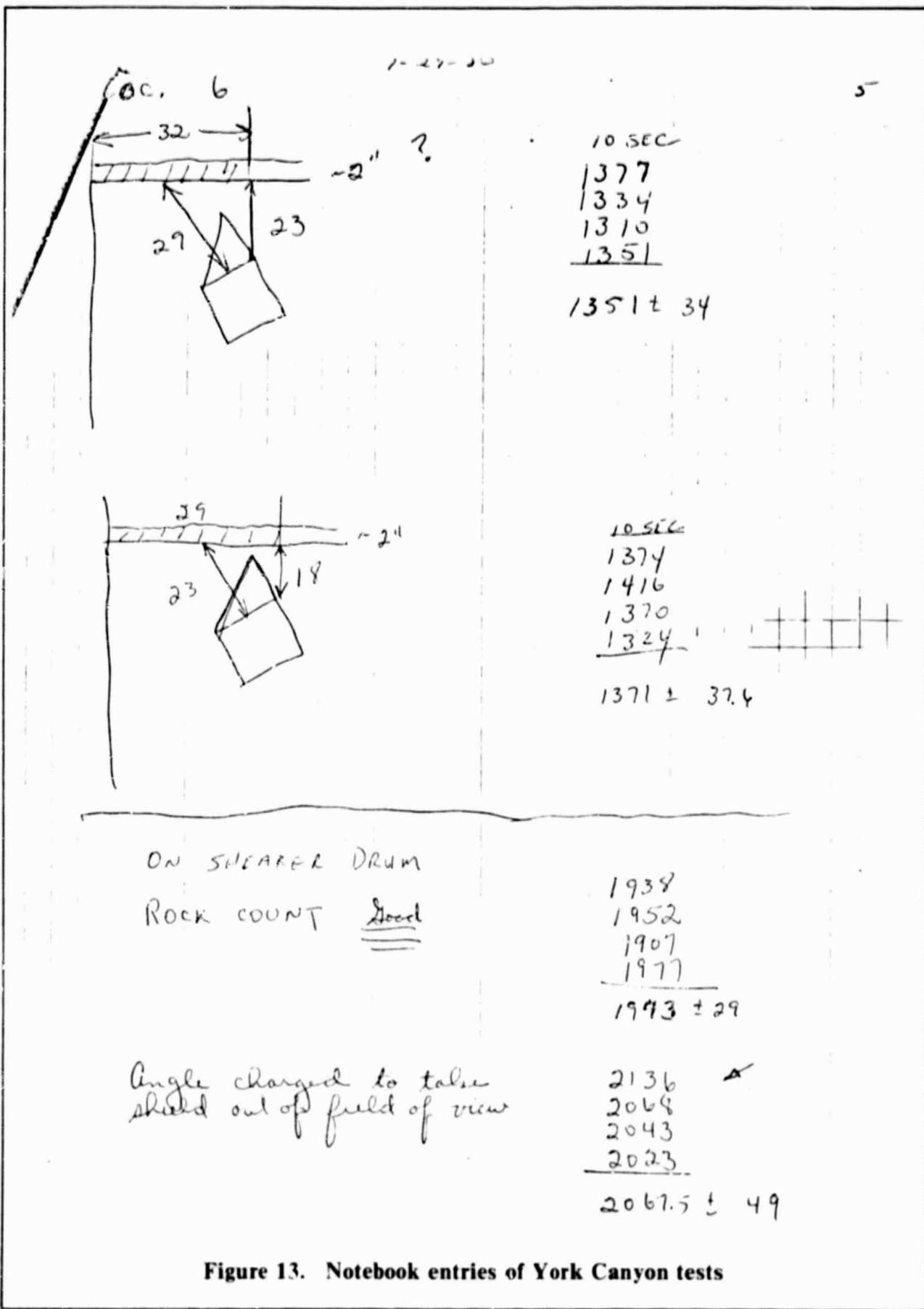


Figure 13. Notebook entries of York Canyon tests

8-25-80

YORK CANYON MINE

CALIBRATION

A BARE ROCK (SHALE) LAST OPEN CROSS CUT

10 SEC COUNT W/O WINDOW SHIELD

4112
4234
4306
4258
4266

10 SEC COUNT W WINDOW SHIELD

3849
3741
3891
3844
3762

B HEAD GATE - SENSOR MOUNTED ON SHEARER

BARE ROCK

2850
2821
2838
2905
2848

Figure 14. Notebook entries of York Canyon tests

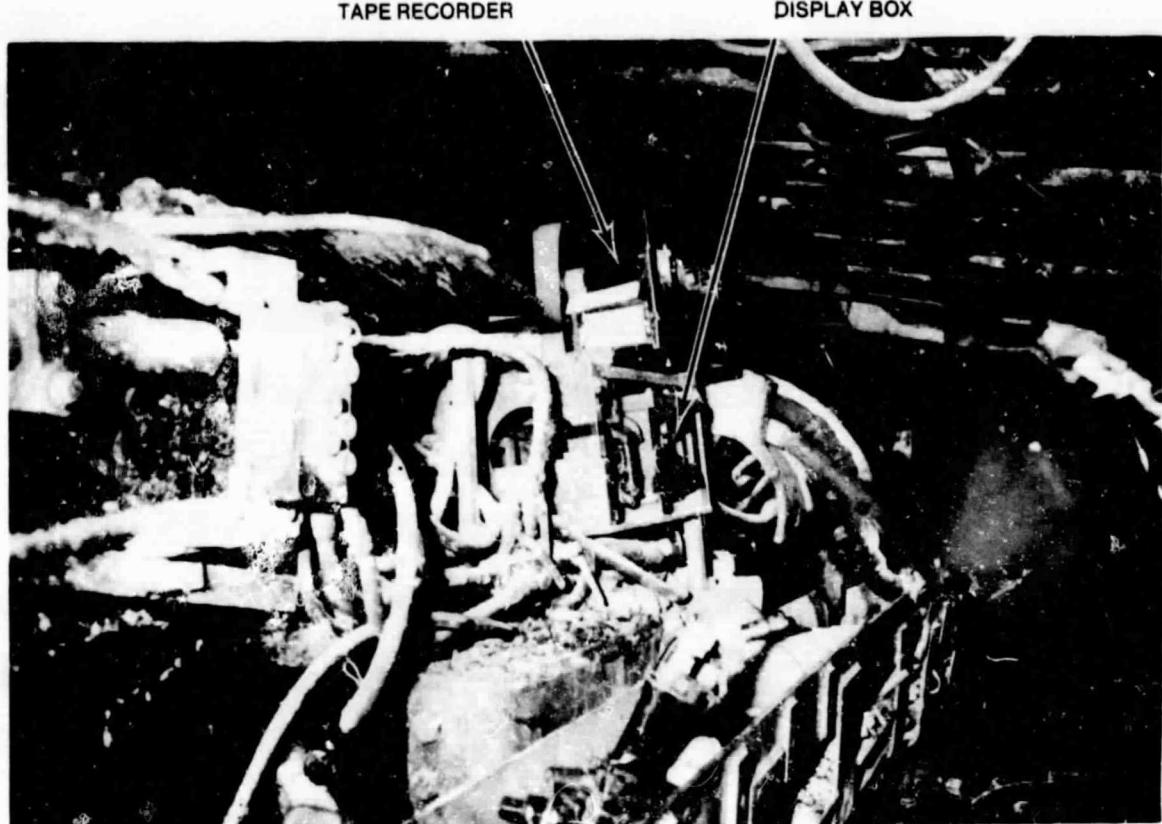


Figure 15. Front view of Anderson shearer at York Canyon mine with display box and tape recorder

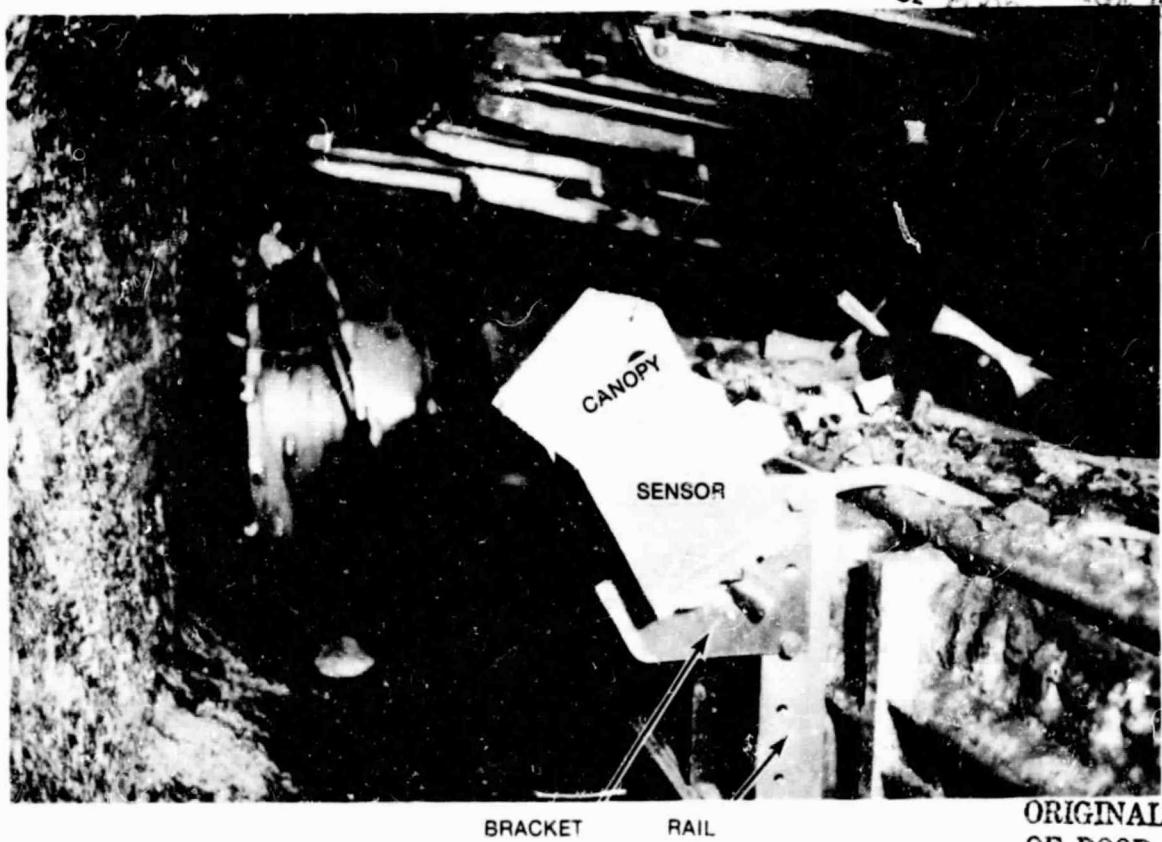


Figure 16. Side view of Anderson shearer at York Canyon showing sensor and bracket mounting

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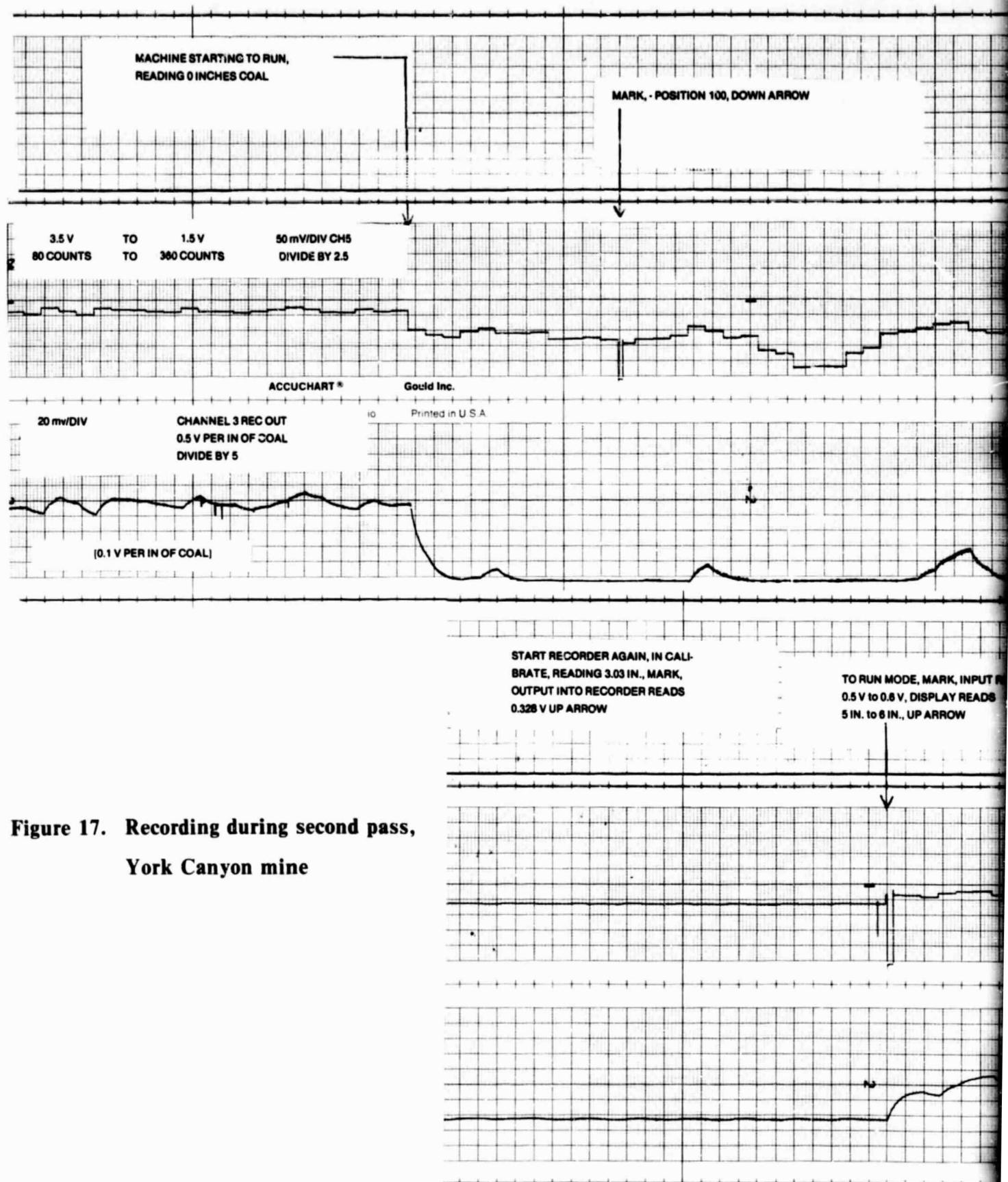
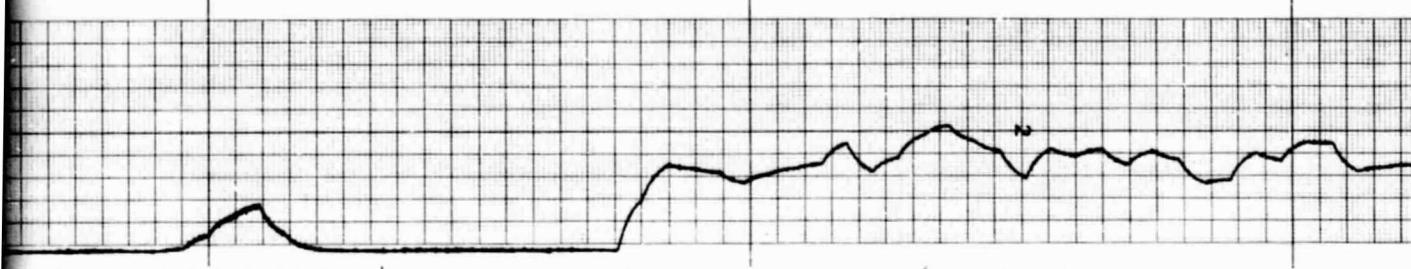


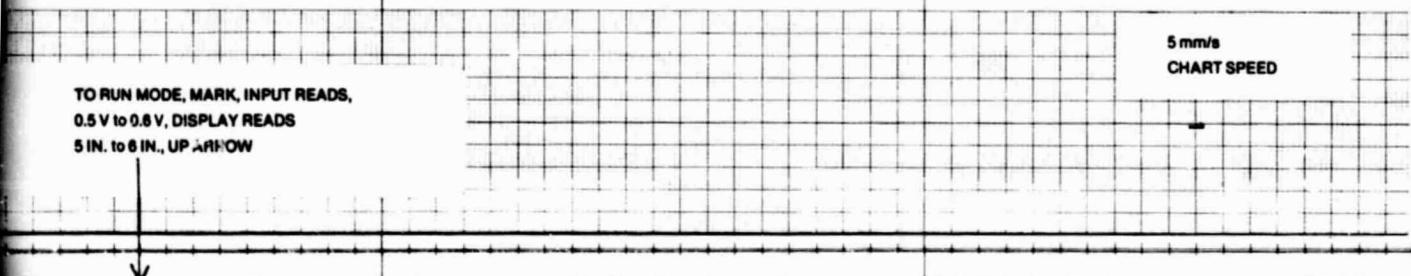
Figure 17. Recording during second pass,
York Canyon mine

FOLDOUT FRAME

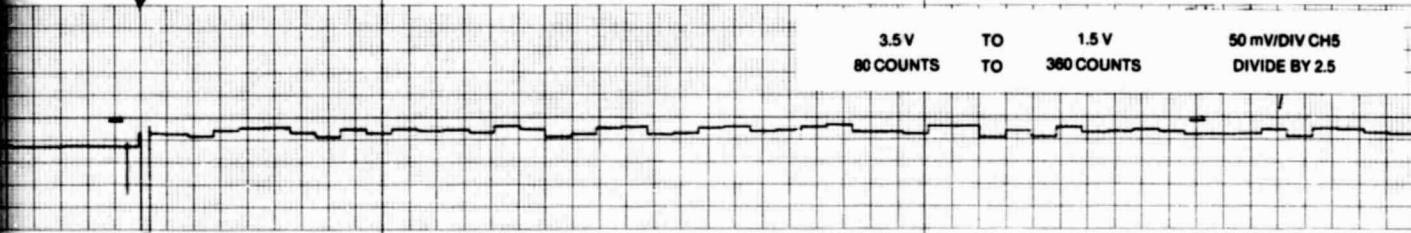
MACHINE STOPPED, READING 5 INCHES
COAL AT POSITION 99
MARK, MARK



5 mm/s
CHART SPEED



3.5 V TO 1.5 V 50 mV/DIV CH5
80 COUNTS TO 360 COUNTS DIVIDE BY 2.5



ACCUCHART® Gould Inc.

Cleveland, Ohio

Printed in U.S.A.

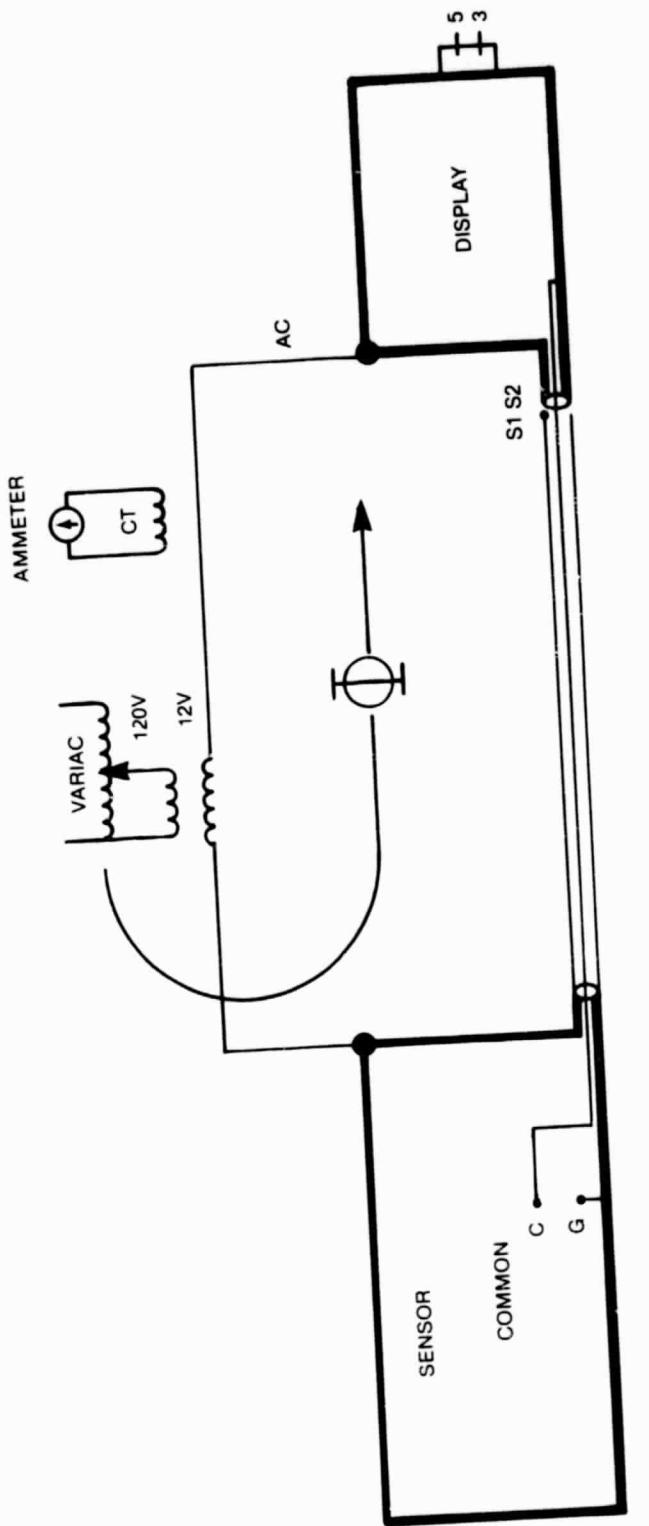
1V CALIBRATION

20 mV/DIV

CHANNEL 3 REC OUT
0.5 V PER IN OF COAL
DIVIDE BY 5

[0.1 V PER IN OF COAL]

FOLDOUT FRAME ?



1	S1	S2	open	C to G	(YORK CANYON)
2	S1	S2	tied	C to G	
3	S1	S2	tied	C-G open	

Figure 18. Shielding configurations

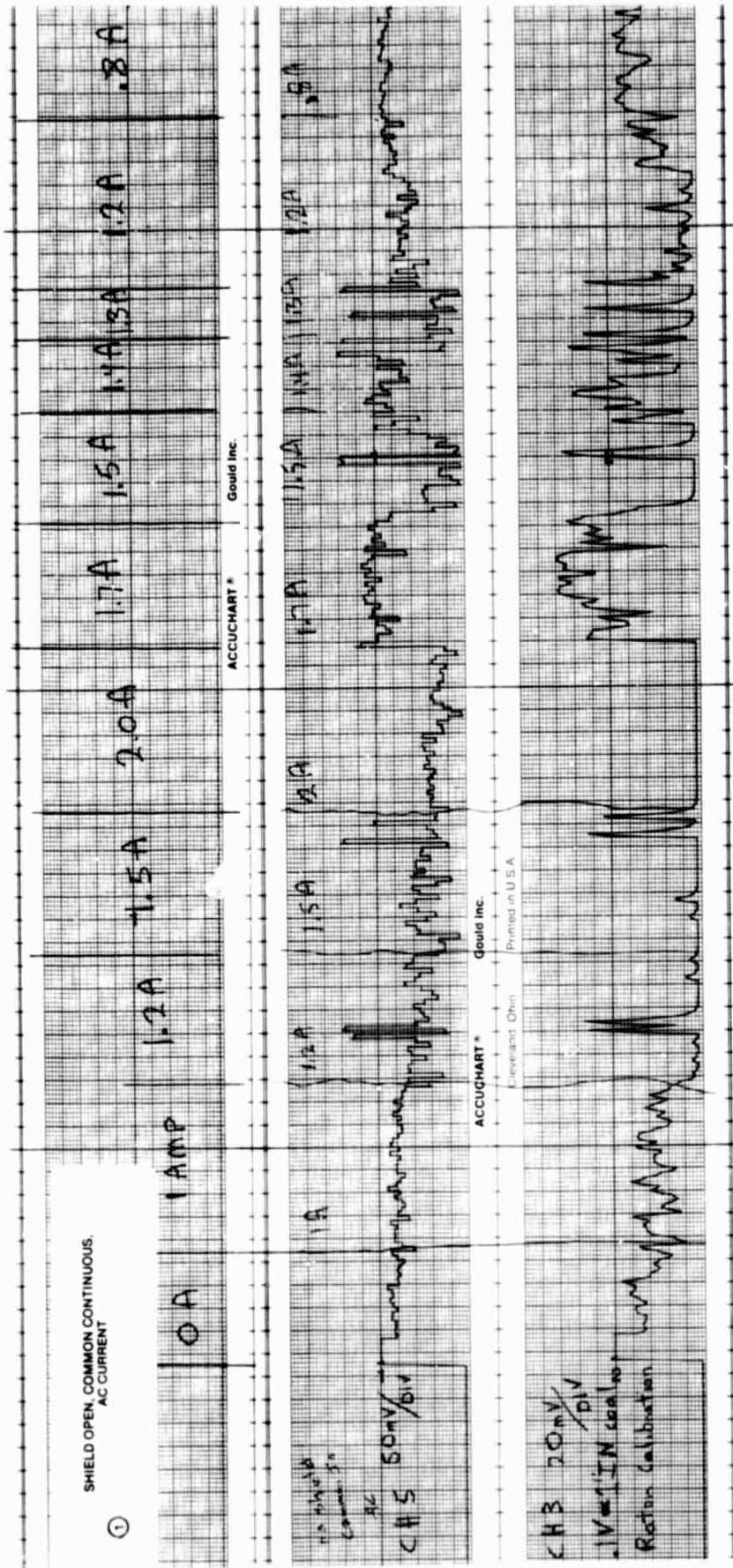
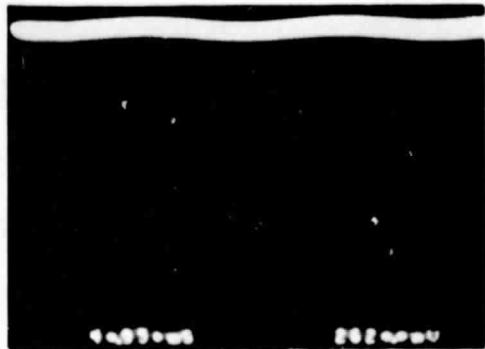


Figure 19. Effect of 60 Hz circulating current

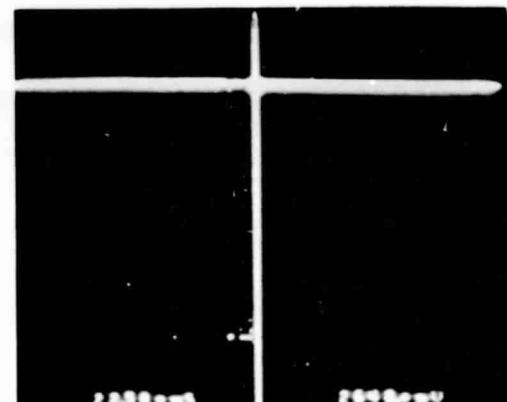
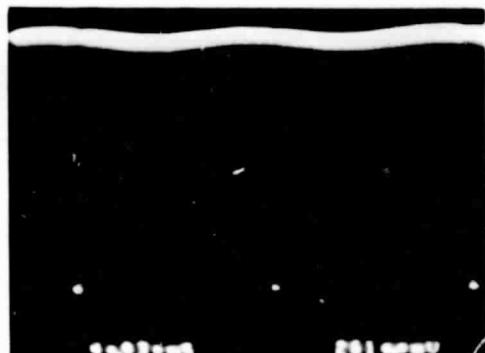
DISCRIMINATOR OUTPUT WITH 60 Hz CURRENT

SHIELD OPEN, COMMON TO CASE

0.9 A



1.2 A



1.5 A

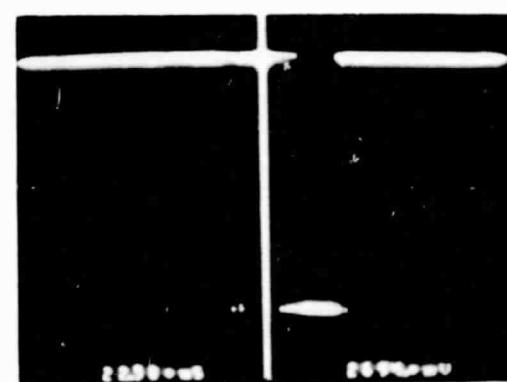
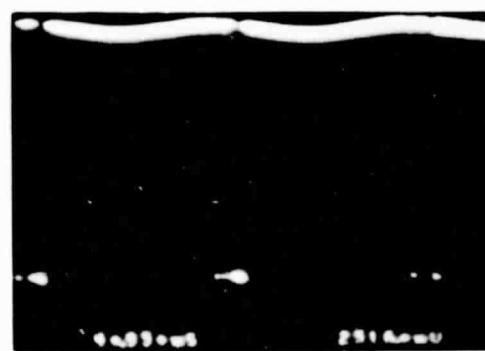
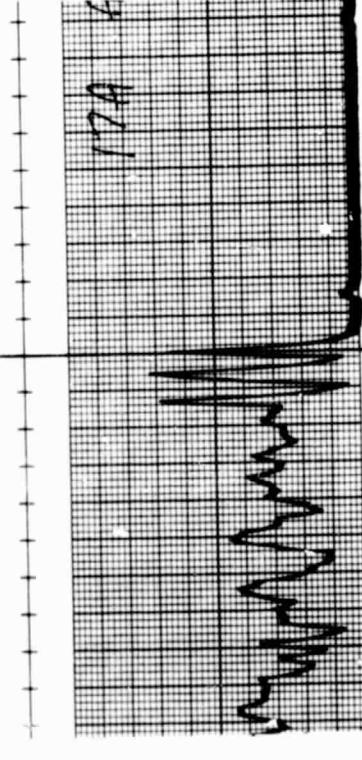
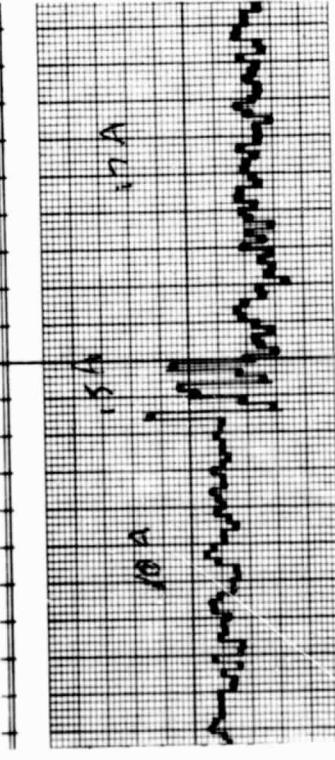
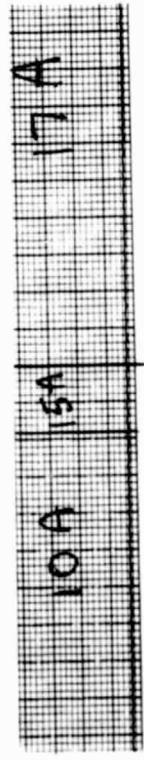


Figure 20. Digital storage oscilloscope recordings of 60 Hz interference

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SHIELD AND COMMON CONTINUOUS,
AC CURRENT

②



SHIELD CONTINUOUS, COMMON
ISOLATED, AC CURRENT

③

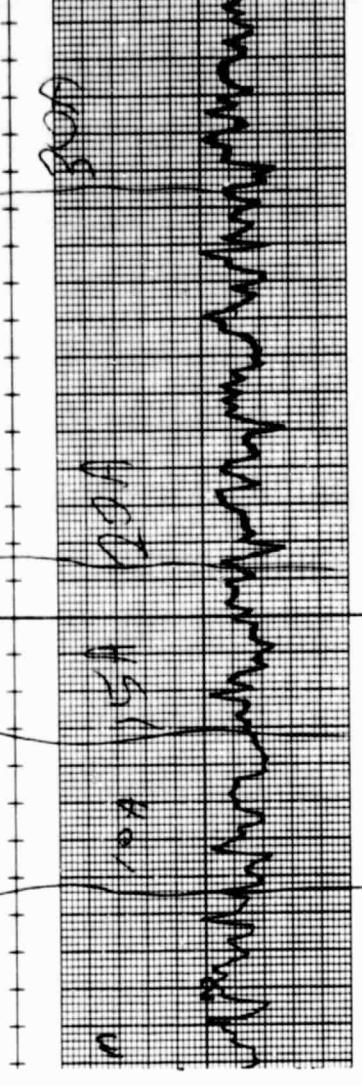
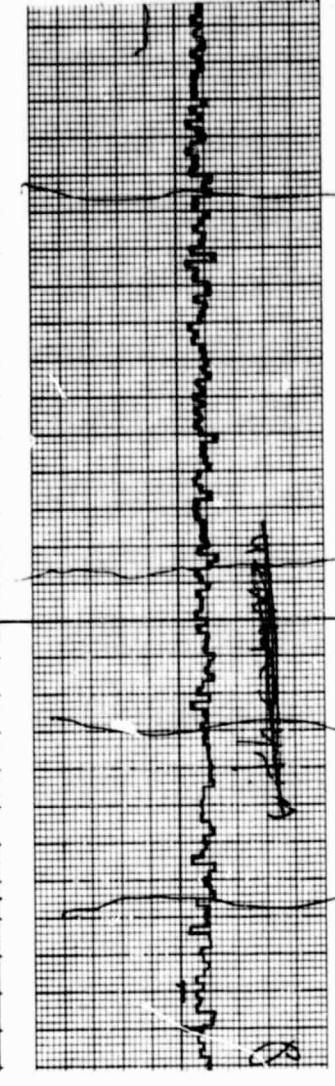
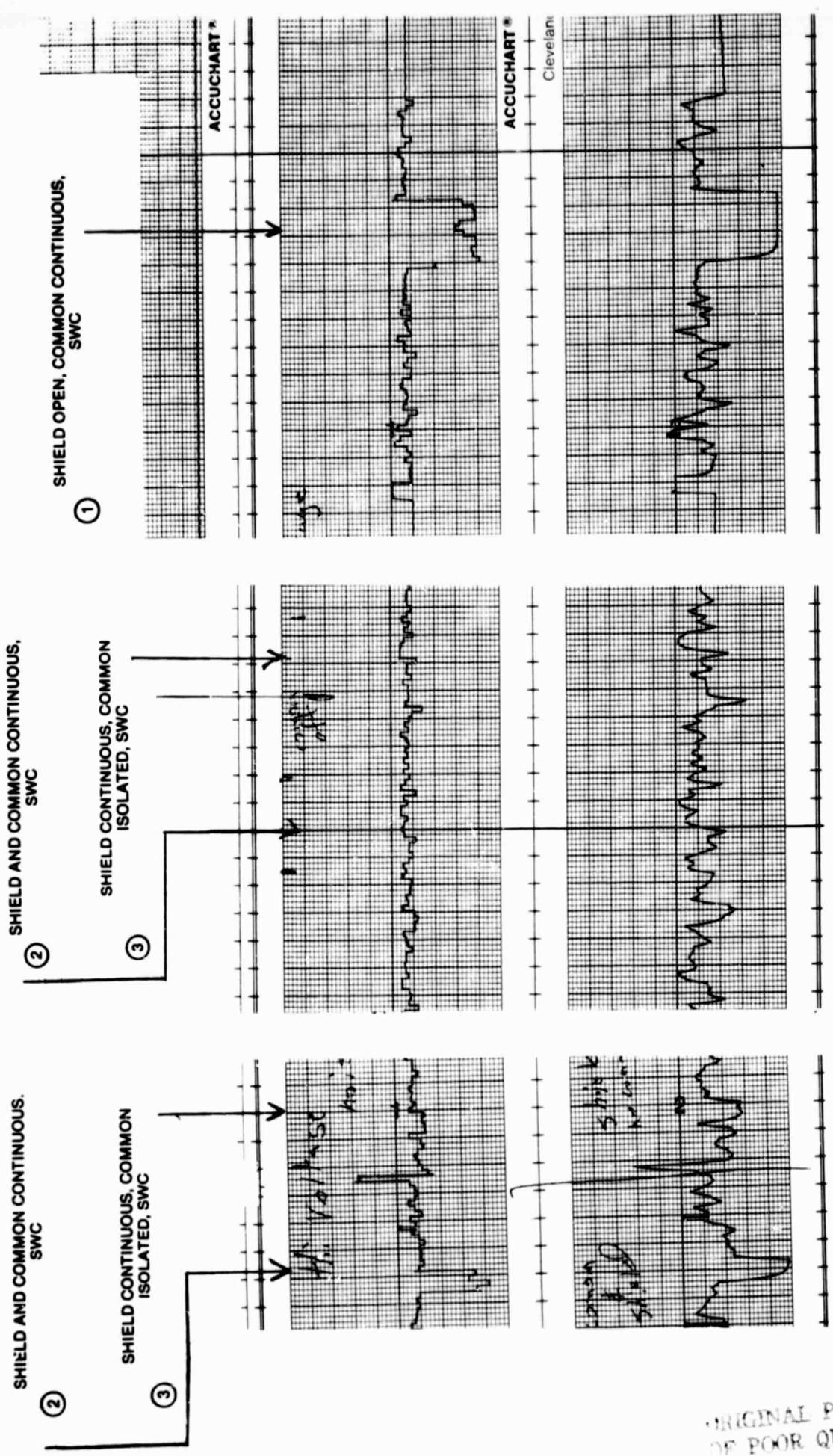


Figure 21. Input noise immunity



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Figure 22. Noise susceptibility to 1 MHz bursts

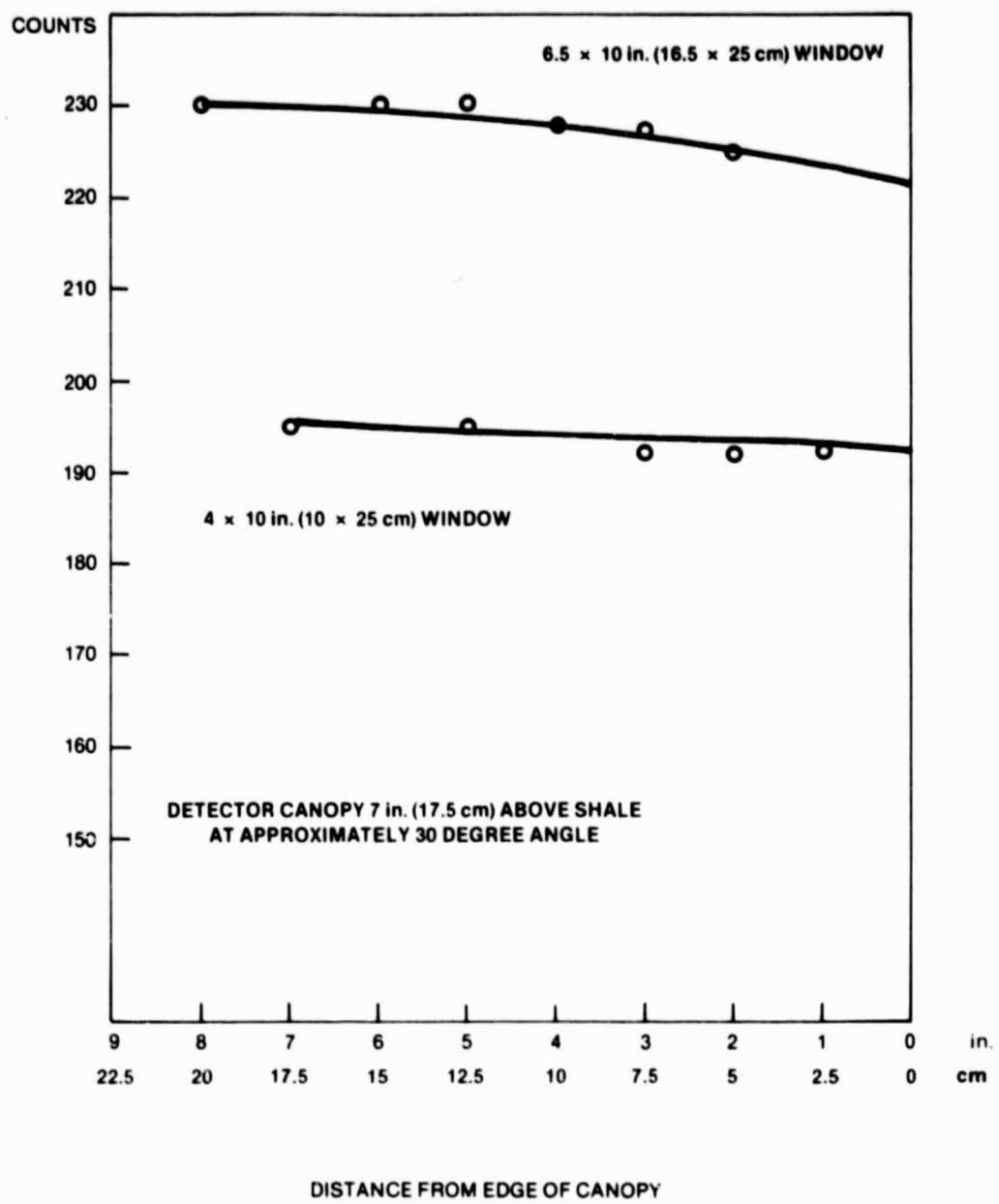


Figure 23. Effect of tighter collimation in total count rate and onset of beam edge cutoff